Streamflow Gains and Losses in the Snake River and Ground-Water Budgets for the Snake River Plain, Idaho and Eastern Oregon

By L.C. KJELSTROM

REGIONAL AQUIFER SYSTEM ANALYSIS—SNAKE RIVER PLAIN, IDAHO

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program was started in 1978 following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which in aggregate underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and accordingly transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies, both to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities, and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number, and where the volume of interpretive material warrants, separate topical chapters that consider the principal elements of the investigation may be published. The series of RASA interpretive reports begins with Professional Paper 1400 and thereafter will continue in numerical sequence as the interpretive products of subsequent studies become available.

Gordon P. Eaton

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
acre	4,047	square meter (m^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	.0283	cubic meter per second (m^3/s)
foot (ft)	.3048	meter (m)
foot per day (ft/d)	.3048	meter per day (m/d)
foot per year (ft/yr)	.3048	meter per year (m/yr)
foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
gallon per minute (gal/min)	.0631	liter per second (L/s)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
square foot (ft^2)	.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in °F (degrees Fahrenheit) can be converted to °C (degrees Celsius) as follows:

$$°C = 5/9\,(°F - 32)$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in report:

µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/L	milligrams per liter

STREAMFLOW GAINS AND LOSSES IN THE SNAKE RIVER AND GROUND-WATER BUDGETS FOR THE SNAKE RIVER PLAIN, IDAHO AND EASTERN OREGON

By L.C. Kjelstrom

ABSTRACT

The Snake River is the regional drain for streams and aquifers in the Snake River basin upstream from Weiser, Idaho. The interaction between the river and ground water was quantified as streamflow gains from and losses to the aquifers. Upstream from Milner, Idaho, the Snake River both gains and loses water. Some reaches gain or lose throughout the year; other reaches gain during the irrigation season when ground-water levels rise as a result of application of surface water for irrigation but lose during the rest of the year. The largest continuous streamflow gain upstream from Milner is from springs between Blackfoot and Neeley, where in 1980 the Snake River gained 1.9 million acre-feet of ground water. Downstream from Milner, the Snake River is a gaining stream. Gains are largest between Milner and King Hill, where numerous springs discharge to the river. In 1980, the Snake River gained 4.7 million acre-feet of ground water between Milner and King Hill.

Although large springs were present in the Blackfoot-to-Neeley and Milner-to-King Hill reaches before irrigation began on the plain, the application of surface water for irrigation increased recharge to the Snake River Plain aquifer; therefore, spring discharge to both reaches also increased. However, despite changes in irrigated acreage and corresponding changes in the amount of water potentially available for recharge, spring discharge between Blackfoot and Neeley has remained relatively stable for 69 years (1912–80). During the same period, discharge from individual springs and total ground-water discharge between Milner and King Hill have increased and decreased substantially in quantities that can be attributed to changes in irrigation.

The changes in ground-water recharge and discharge and ground-water storage generally are the net result of 100 successive years of irrigation on the Snake River Plain. Water-budget analyses indicate that the total volume of ground water in storage in the main part of the eastern Snake River Plain increased about 24 million acre-feet from 1880 to 1952, largely as a result of increased recharge in areas irrigated with surface water. The total volume of ground water in storage decreased about 6 million acre-feet from 1952 to 1980 as a result of several years of below-normal precipitation, increased pumping of ground water for irrigation, and other changes in irrigation practices. Ground-water storage in parts of the western Snake River Plain increased about 3 million acre-feet from 1930 to 1972 but generally has decreased since 1972.

INTRODUCTION

The Snake River Plain Regional Aquifer-System Analysis (RASA) study began in October 1979 and is one in a series of studies designed to investigate the quantity and quality of water in regional aquifer systems in the United States. The main purposes of the overall study were to (1) refine knowledge of regional ground-water-flow systems, (2) determine effects of conjunctive uses of ground and surface water, and (3) describe ground-water chemistry (Lindholm, 1981).

Lindholm (1981) presented a plan of study for the Snake River Plain RASA. Preliminary interpretive reports generated during the RASA study (1988) include (1) a regional water-table map and description of the ground-water-flow system (Lindholm and others, 1983, 1988); (2) a description of the geohydrologic framework (Whitehead and Lindholm, 1985; Whitehead, 1986); (3) water budgets and streamflow in the Snake River (Kjelstrom, 1986); (4) water withdrawals for irrigation (Bigelow and others, 1986); (5) a map showing irrigated land and other land uses (Lindholm and Goodell, 1986); (6) a description of solute distribution in ground and surface water (Low, 1987); and (7) results of ground-water-flow modeling of the eastern Snake River Plain (Garabedian, 1986).

Final results of the Snake River Plain RASA study are presented in Professional Paper 1408, which consists of seven chapters as follows:

Chapter A is a summary of the aquifer system.

Chapter B describes the geohydrologic framework, hydraulic properties of rocks composing the framework, and geologic controls on ground-water movement.

Chapter C (this report) describes streamflow gains and losses in the Snake River and ground-water budgets for the Snake River Plain.

Chapter D describes solute geochemistry of the cold-water and geothermal-water systems.

Chapter E describes water use.

Chapter F describes results of ground-water-flow modeling of the eastern Snake River Plain.

Chapter G describes results of ground-water-flow modeling of the western Snake River Plain.

The Snake River Plain occupies nearly 23 percent of the 69,200 mi^2 Snake River basin upstream from Weiser, Idaho (pl. 1). The plain extends along the central part of the basin across southern Idaho and into eastern Oregon. It ranges in width from 30 to 75 mi and decreases in altitude from 6,000 to 2,100 ft above sea level from east to west. The areal extent of the Snake River Plain, as defined in this RASA study, is based on geology and topography. Generally, the plain's boundary is the contact between the Quaternary sedimentary and volcanic rocks that form the plain and the surrounding Tertiary and older rocks. Where rocks equivalent in age to those in the plain extend beyond the plain's boundary (for example, where the boundary crosses the mouth of a tributary valley such as the Big Lost River valley; pl. 1), a topographic contour was chosen to define the boundary. Mountains surrounding the plain range in altitude from 7,000 to 12,000 ft above sea level. All surface- and ground-water discharge in the basin is to the Snake River.

For discussion purposes, the Snake River Plain is subdivided into two geographic parts, the eastern plain and the western plain (pl. 1). The boundary between the eastern and western plain is near King Hill, where differences in geology and hydrology of the area are distinct. The eastern plain (10,800 mi^2) is underlain by a thick sequence of volcanic rocks that store and yield large volumes of water. The western plain (4,800 mi^2), in western Idaho and eastern Oregon, is underlain by lacustrine and fluviatile rocks that include thick ash beds. Aquifers that underlie the western plain generally yield much smaller volumes of water than the basalt aquifers that underlie the eastern plain.

PURPOSE AND SCOPE

The purposes of this report are to (1) quantify streamflow gains and losses in the Snake River, (2) determine early irrigation development and recent (1980) ground-water budgets for the Snake River Plain, and (3) evaluate historical changes in the ground-water-flow system due to development.

Monthly streamflow gains from and losses to the ground-water-flow system in 1980 were computed for 15 reaches of the Snake River; annual gains and losses were computed for 12 reaches. Streamflow gains and losses were quantified to improve understanding of the ground-water-flow system and to assess whether and how changes in either the ground- or surface-water-flow system affect each other.

Water budgets were developed to help quantify these relations and to aid in developing conceptual and digital models of the ground-water-flow system. Budgets were used to analyze the effects of climatological changes, increases in irrigated acreage, changes in irrigation practices, and combinations of these changes on the ground-water-flow system. Budgets also were used to determine trends of changes in ground-water storage.

Annual ground-water budgets from 1912 to 1980 were developed for the eastern plain and from 1930 to 1980 for the western plain. Changes in ground-water storage during these two periods were compared with changes in ground-water levels.

PREVIOUS INVESTIGATIONS

The first water budget for the Snake River basin upstream from Weiser was presented by Stearns and others (1938). Mundorff and others (1964) estimated recharge to the ground-water-flow system in the eastern plain from tributary drainage basins and surface-water-irrigated areas. They also presented a water-table map and flow net of the regional ground-water-flow system. Among the references listed by Mundorff and others (1964) were 31 reports describing geology and ground-water resources of the Snake River Plain. Possible changes in the hydrologic system that might result from the use of ground water for irrigation and the potential for artificial recharge in the eastern plain were studied by Norvitch and others (1969).

Water budgets for the eastern and western parts of the plain were described by Kjelstrom (1986). Annual mean water yield to the Snake River Plain from tributary drainage basins was determined for water years 1934–80 by using stream-discharge records directly, by correlation with records of nearby streamflow-gaging stations (hereafter called gaging stations), or by regional regression analysis. Water yield from tributary drainage basins includes streamflow and ground-water discharge to the Snake River Plain aquifer system.

CLIMATE

The climate of the Snake River Plain is semiarid; average annual precipitation on much of the plain is

TABLE 1.—*Mean monthly and annual precipitation at selected locations, water years 1951–80*

[Modified from National Oceanic and Atmospheric Administration, 1951–80]

Site No. (shown on pl. 1)	Weather station	Altitude (feet)	Mean precipitation (inches)												
			Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
							Eastern Plain								
C1	Ashton	5,260	1.29	1.78	2.19	2.21	1.85	1.47	1.41	1.86	1.90	0.79	1.22	1.17	19.14
C2	Dubois	5,452	.67	.89	.92	.72	.73	.71	.94	1.59	1.84	.91	.99	1.02	11.93
C3	Idaho Falls	4,730	.73	.78	.82	.81	.66	.63	.87	1.27	1.19	.47	.76	.69	9.68
C4	Pocatello	4,454	.86	1.05	.92	1.11	.86	1.01	1.07	1.36	1.13	.42	.60	.60	10.99
C5	Burley	4,146	.60	.90	1.03	1.23	.76	.76	.93	1.18	.96	.36	.38	.52	9.61
C6	Oakley	4,600	.67	.87	.90	.94	.63	.87	1.09	1.70	1.45	.77	.93	.75	11.57
C7	Twin Falls	3,960	.67	.94	1.08	1.20	.77	.87	.84	1.14	.86	.25	.42	.55	9.59
C8	Bliss	3,275	.51	1.20	1.36	1.52	.92	.74	.70	.95	.82	.20	.31	.47	9.70
							Western Plain								
C9	Boise	2,838	.82	1.26	1.35	1.46	1.19	1.07	1.18	1.30	1.00	.23	.38	.49	11.73
C10	Parma	2,215	.83	1.27	1.43	1.65	1.05	.97	.92	1.08	.97	.21	.57	.68	11.63

8 to 10 in. The source of most precipitation on the plain is airmasses moving inland from the Pacific Ocean, but moisture-laden air from the Gulf of Mexico and the Caribbean region produces thunderstorms in the summer, particularly in eastern Idaho (National Oceanic and Atmospheric Administration, 1976, p. 3). Climate in the eastern plain is more continental than that in the western plain; the range in summer and winter temperatures is greater, and more precipitation falls in the summer. Average annual precipitation is greatest on the northeastern end of the plain, where land-surface altitude exceeds 6,000 ft. Table 1 shows mean monthly and annual precipitation measured at weather stations on or near the Snake River Plain (National Oceanic and Atmospheric Administration, 1951–80).

Precipitation on the plain is inadequate for most crops; thus, irrigation is needed. Runoff from mountains bordering the plain is the most readily available source of water for irrigation; additional irrigation water is obtained from surface reservoirs and aquifers.

Although most long-term weather stations are on or near the plain (locations on pl. 1), precipitation rates do not always correlate with rates of runoff from bordering mountains (Kjelstrom, 1986). Therefore, water yield to the plain from bordering mountains was determined on the basis of streamflow records.

Snow accumulates in the mountains generally from November to March, and runoff from snowmelt usually takes place from April through July. The U.S. Soil Conservation Service measures snow depths and calculates equivalent inches of water in the mountain snowpack. Average equivalent inches of water for snowpack at selected snow-course stations are shown in table 2, and snow-course stations are shown on plate 1.

Normally, snow accumulation on the plain is only a few inches; however, in the northeastern part of the plain, snow accumulation may exceed 1 ft. The probability of snow on the ground at the end of each month at weather stations on the plain during the period November to March is shown in table 3. Snow on the plain, in tributary drainage basins, and on low-lying mountains melts during the winter when warm, moist airmasses move inland from the Pacific coast. Melting snow can release greater amounts of water than any single precipitation event during the year (Frederick and Tracey, 1976, p. 1).

Windstorms during October to July are associated with cyclonic systems. Strong winds during the summer are associated with thunderstorms. Prevailing wind direction usually is from the southwest at Pocatello and from the southeast at Boise. During May through August, prevailing winds for both Pocatello and Boise are from the northwest. Average wind velocities are 10.3 mi/h at Pocatello and 9.0 mi/h at Boise (National Oceanic and Atmospheric Administration, 1976).

Mean annual air temperature at weather stations on the plain (table 4) ranges from 51.7°F at Boise to

TABLE 2.—*Average water content of snowpack in mountainous areas bordering the Sanke River Plain, 1961–85*

[Modified from U.S. Soil Conservation Service, 1988]

Site No. (shown on pl. 1)	Snow-course station	Drainage basin	Altitude (feet)	Equivalent inches of water at beginning of month				
				Jan.	Feb.	Mar.	Apr.	May
		Eastern Plain						
S1	Big Springs	Henrys Fork	6,400	8.3	14.0	18.4	21.4	16.2
S2	Grassy Lake	Henrys Fork	7,270	15.1	24.0	30.3	36.2	34.9
S3	Island Park	Henrys Fork	6,290	6.8	11.6	15.2	17.3	10.3
S4	Pine Creek Pass	Teton River	6,810	7.2	11.6	15.4	17.8	12.7
S5	Kilgore	Camas Creek	6,320	4.7	8.2	10.7	11.8	(1)
S6	Howell Canyon	Marsh Creek	7,980	11.6	18.2	22.9	26.7	23.5
S7	Galena Summit	Big Wood River	8,780	11.0	16.4	20.2	24.4	25.8
		Western Plain						
S8	Trinity Mountain	Boise River	7,770	19.6	29.3	37.0	42.8	43.7
S9	Mores Creek Summit	Boise River	6,100	13.9	22.6	28.2	33.0	31.7
S10	Bogus Basin	Payette River	6,340	9.9	16.7	20.9	25.2	22.5
S11	South Mountain	Owyhee River	6,500	6.3	10.1	12.6	14.7	8.2

[1] Undetermined.

TABLE 3.—*Probability of snow on the ground at the end of each month at selected locations*

[Modified from Pacific Northwest River Basins Commission, 1969; —, no data available]

Site No. (shown on pl. 1)	Weather station	Altitude (feet)	Percentage probability				
			Nov.	Dec.	Jan.	Feb.	Mar.
		Eastern Plain					
C1	Ashton	5,260	71	97	97	91	86
C2	Dubois	5,452	6	91	97	79	27
C3	Idaho Falls	4,730	23	75	87	71	39
C4	Pocatello	4,454	19	48	57	33	7
C5	Burley	4,146	—	—	—	—	—
C6	Oakley	4,600	6	31	33	15	6
C7	Twin Falls	3,960	3	26	41	6	3
C8	Bliss	3,275	9	28	52	21	3
		Western Plain					
C9	Boise	2,838	4	23	46	>1	>1
C10	Parma	2,215	—	—	—	—	—

TABLE 4.—*Mean annual air temperatures at selected locations, 1951–73*

Site No. (shown on pl. 1)	Weather station	Altitude (feet)	Mean temperature (degrees Fahrenheit)		
			Jan.	July	Annual
		Eastern Plain			
C1	Ashton	5,260	18.6	63.9	41.0
C2	Dubois	5,452	18.4	68.7	42.6
C3	Idaho Falls	4,730	19.6	68.9	44.0
C4	Pocatello	4,454	23.2	71.5	46.7
C5	Burley	4,146	27.3	70.8	47.7
C6	Oakley	4,600	29.5	70.8	48.8
C7	Twin Falls	3,960	29.4	72.7	49.6
C8	Bliss	3,275	29.3	73.9	50.4
		Western Plain			
C9	Boise	2,838	31.2	73.4	51.7
C10	Parma	2,215	29.3	73.4	50.5

41.0°F at Ashton (National Oceanic and Atmospheric Administration, 1976). July is the warmest month and January the coldest. Evaporation generally is greatest during July and least during January. Temperature correlates well with altitude and latitude. Growing season also is related to altitude and latitude.

Average dates of the last freezing temperature in the spring and the first in the fall at several weather stations on or near the plain are given in table 5. The number of days between the two dates approximates the length of the growing season. Generally, the length of the growing season determines the types of crops that can be raised and the amount of water needed for irrigation.

TABLE 5.—*Average beginning and ending dates of freezing temperatures, 1931–65, and length of growing season at selected locations*

Site No. (shown on pl. 1)	Weather station	Altitude (feet)	Average date of last freeze in spring	Average date of first freeze in fall	Length of growing season (days)
		Eastern Plain			
C1	Ashton	5,260	June 10	Sept. 4	86
C2	Dubois	5,452	May 27	Sept. 22	118
C3	Idaho Falls	4,730	May 22	Sept. 21	122
C4	Pocatello	4,454	May 10	Sept. 29	142
C5	Burley	4,146	May 9	Oct. 3	147
C6	Oakley	4,600	May 25	Sept. 24	122
C7	Twin Falls	3,960	May 13	Sept. 24	134
C8	Bliss	3,275	May 20	Sept. 24	127
		Western Plain			
C9	Boise	2,838	May 6	Oct. 12	159
C10	Parma	2,215	May 7	Sept. 28	144

DEVELOPMENT OF WATER RESOURCES

Fur trade brought travelers to the Snake River Plain in the 1840's, and land was first irrigated near the settlements of Boise and Fort Hall. When the gold rush in the Boise Basin began in 1862, easily irrigated land along the Boise River was put into agricultural production. Organized irrigation projects began in 1863 and, by 1880, about 80,000 acres in the Boise River valley were irrigated. By 1880, rights for Snake River water for irrigation on the eastern plain totaled about 200 ft^3/s. Initial irrigation on the eastern plain was mostly along the Henrys Fork, the Snake River upstream from Blackfoot, and the Teton River. Congressional actions such as the Desert Land Act of 1877, a survey of irrigable lands in 1889, and the Carey Act of 1894 encouraged reclamation of arid land (Lindholm and Goodell, 1986). The amount of irrigated land increased rapidly after 1895 as diversion works and canals were completed. By 1905, rights for Snake River water for irrigation on the eastern plain had increased to nearly 20,000 ft^3/s. During the 1905 irrigation season, a 10-mi reach of the Snake River near Blackfoot had no streamflow for several days—evidence that demand for Snake River water had exceeded natural streamflow. Subsequently, dams were constructed to store water for later use. Many of the dams also were built for flood control and hydroelectric-power generation.

The approximate increase in irrigated acreage from 1910 to 1980 is shown in figure 1. Acreage data are for the plain and areas adjacent to the plain that are irrigated with water from Mackay, Salmon Falls Creek, and Oakley Reservoirs (pl. 1). Because amounts of irrigated land were not documented annually, amounts for many years were estimated. Lands that could be supplied by gravity diversions were put into production first. Lands near the margins of irrigation tracts, at the downstream ends of delivery systems, and with subordinated water rights were irrigated when water was available.

When surface water was fully appropriated, ground water provided a reliable alternate supply for irrigation in many areas. Irrigation with ground water increased substantially during the late 1940's and continued to increase during the 1950's and 1960's; the rate of increase slowed during the 1970's. During the 1970's, pumping from the Snake River for irrigation increased substantially.

Surface-water diversions by gravity decreased during the late 1970's when almost 20 percent of the irrigation distribution systems were converted from flood and furrow to sprinklers, a more efficient irrigation system. As a result, evaporation losses and deep percolation were reduced.

Analysis of 1980 Landsat data (Lindholm and Goodell, 1986) indicated that 3.1 million acres were irrigated on the Snake River Plain—2.0 million acres with surface water, about 1.0 million acres with ground water, and 0.1 million acres with a combination of surface and ground water (fig. 2).

Bigelow and others (1986) reported that, in 1980, about 2.3 million acre-ft of water was pumped from about 5,300 irrigation wells on the Snake River Plain. About 84 percent of the total was pumped on the eastern plain. Most high-yield wells are completed in basalt, which comprises the major aquifers in the eastern plain. Lindholm (1986, p. 88) estimated that 200 to 300 million acre-ft of water is stored in the top 500 ft of the Quaternary basalt aquifer in the eastern plain.

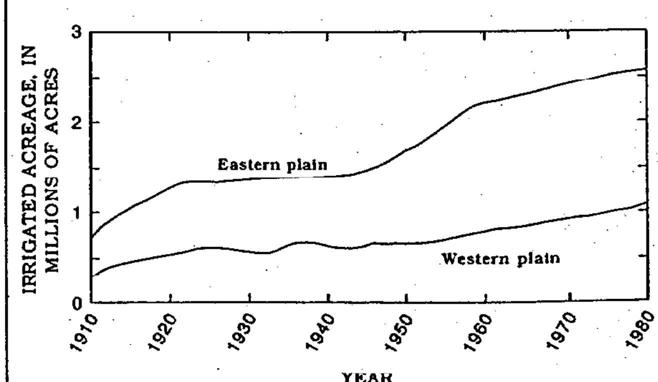


FIGURE 1.—Irrigated acreage on the Snake River Plain, 1910–80.

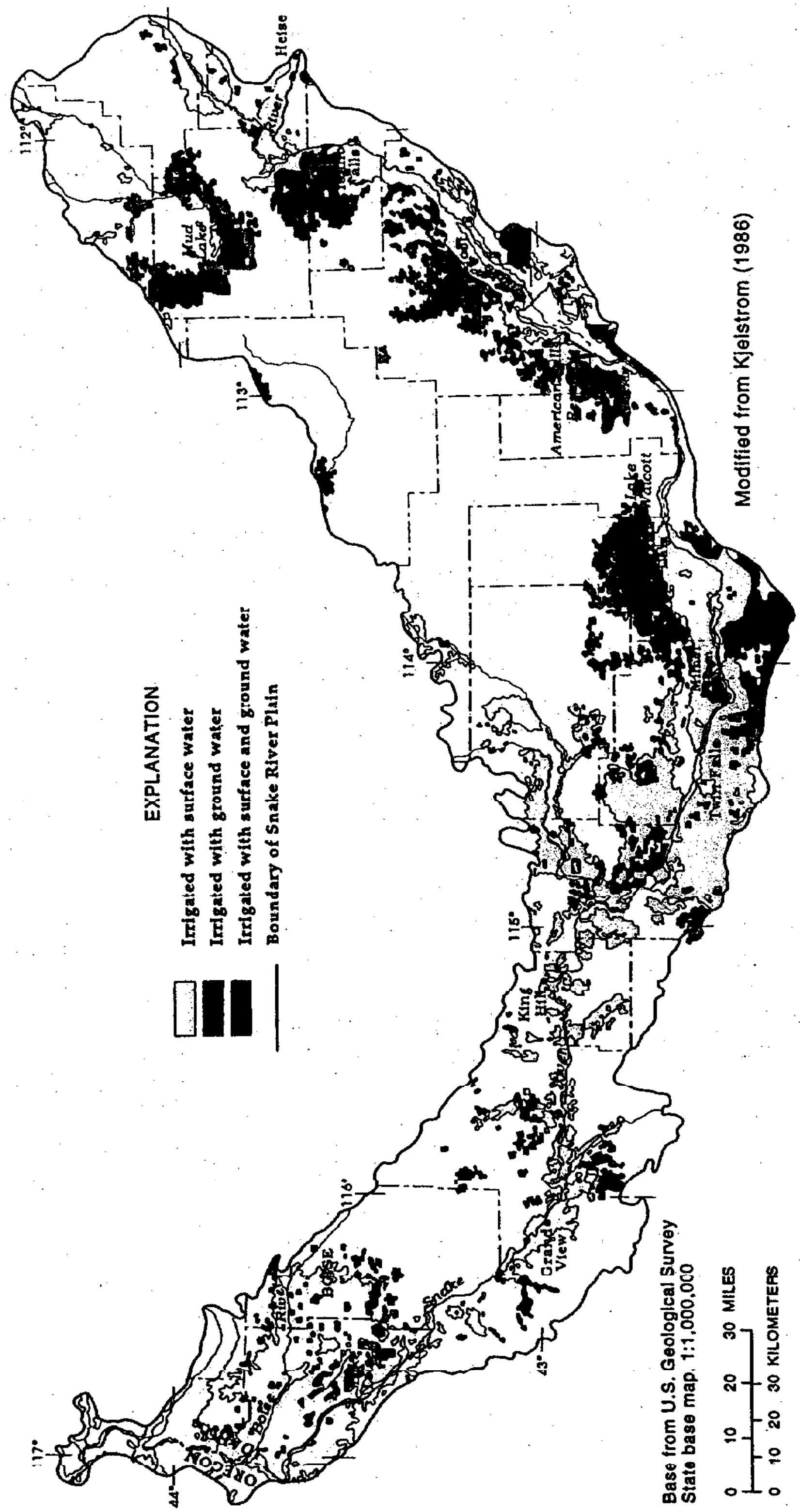


FIGURE 2.—Irrigated land on the Snake River Plain, 1980.

Hydrologic effects of water-resource development are shown by ground-water-level hydrographs (Young and Norvitch, 1984; Garabedian, 1986, 1992; Lindholm and others, 1988; Newton, 1991) and by hydrographs of ground-water discharge, largely from springs (Kjelstrom, 1986). Long-term hydrographs show that ground-water levels initially rose and ground-water discharge to the Snake River increased until the early 1950's as a result of increased recharge from the use of surface water for irrigation. However, from the early 1950's to 1980, ground-water levels generally declined as a result of increased use of ground water for irrigation, decreased use of surface water for irrigation, use of sprinklers, and periods of several years' duration of below-normal precipitation (Lindholm and others, 1988).

IDAHO WELL-NUMBERING SYSTEM

The well-numbering system (fig. 3) used by the U.S. Geological Survey in Idaho indicates the location of wells within the official rectangular subdivision of public lands, with reference to the Boise base line and Meridian. The first two segments of the number designate the township (north or south) and range (east or west). The third segment gives the section number; three letters, which indicate the ¼ section (160-acre tract), ¼-¼ section (40-acre tract), and ¼-¼-¼ section (10-acre tract); and serial number of the well within the tract. Quarter sections are designated by the letters A, B, C, and D in counterclockwise order from the northeast quarter of each section. Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. For example, well 5S-31E-27ABA1 is in the NE¼NW¼NE¼ sec. 27, T. 5 S., R. 31 E., and is the first well inventoried in that tract.

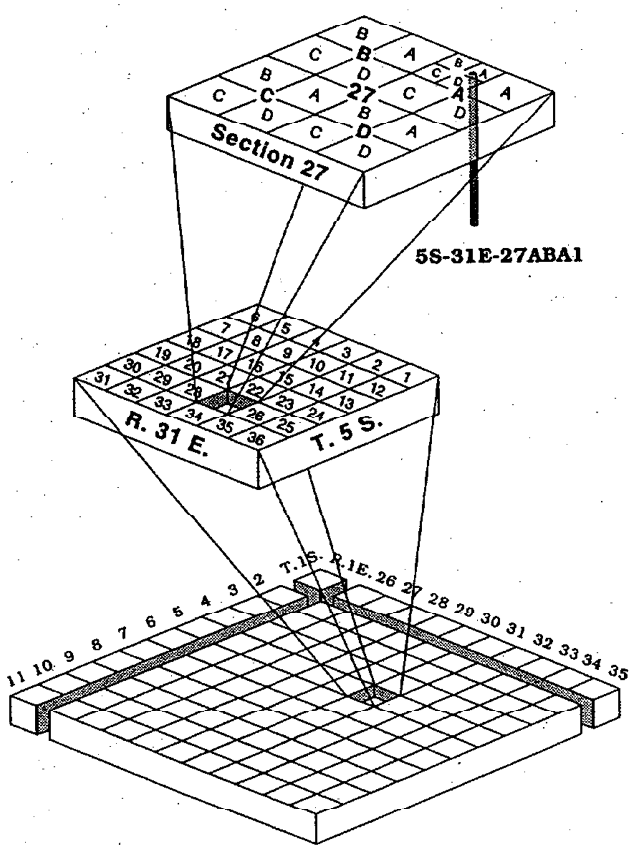


FIGURE 3.—Idaho well-numbering system.

GEOHYDROLOGY

A detailed description of the geohydrologic framework of the Snake River Plain was presented by Whitehead (1992). The eastern Snake River Plain is underlain by a series of Quaternary basalt flows and intercalated pyroclastic and sedimentary rocks; the western plain is underlain by Quaternary and Tertiary sedimentary rocks and a lesser amount of basalt (fig. 4). Tops of individual basalt flows are usually irregular, highly fractured, and rubbly. If the top of a flow is not covered by sediment, the zone between it and a subsequent flow is commonly highly permeable. Collectively, several such zones result in high transmissivity, a characteristic of basalt of the Quaternary Snake River Group. Joints and faults provide vertical hydraulic connections between flows. Faults may, however, cause barriers that impede or change the direction of horizontal movement of ground water. Where basalt is dense, or where silt and clay have filled openings in the basalt, it is less permeable. Mundorff and others (1964, p. 156) summarized the results of several aquifer tests and concluded that basalt of the Snake River Group is highly transmissive and readily yields water to wells. This conclusion is supported by the fact that about 75 percent of 336 irrigation wells completed in basalt of the Snake River Group yield between 900 and 3,300 gal/min (Garabedian, 1992).

The western plain is underlain by Quaternary and Tertiary sedimentary rocks that, in large areas, are predominantly fine grained. Basalt is present in the eastern part of the western plain (fig. 4).

In the western plain, ground water is present in shallow and deep cold-water systems that overlie a geothermal system. Most aquifers are composed of sand and gravel and a lesser amount of basalt. Faults

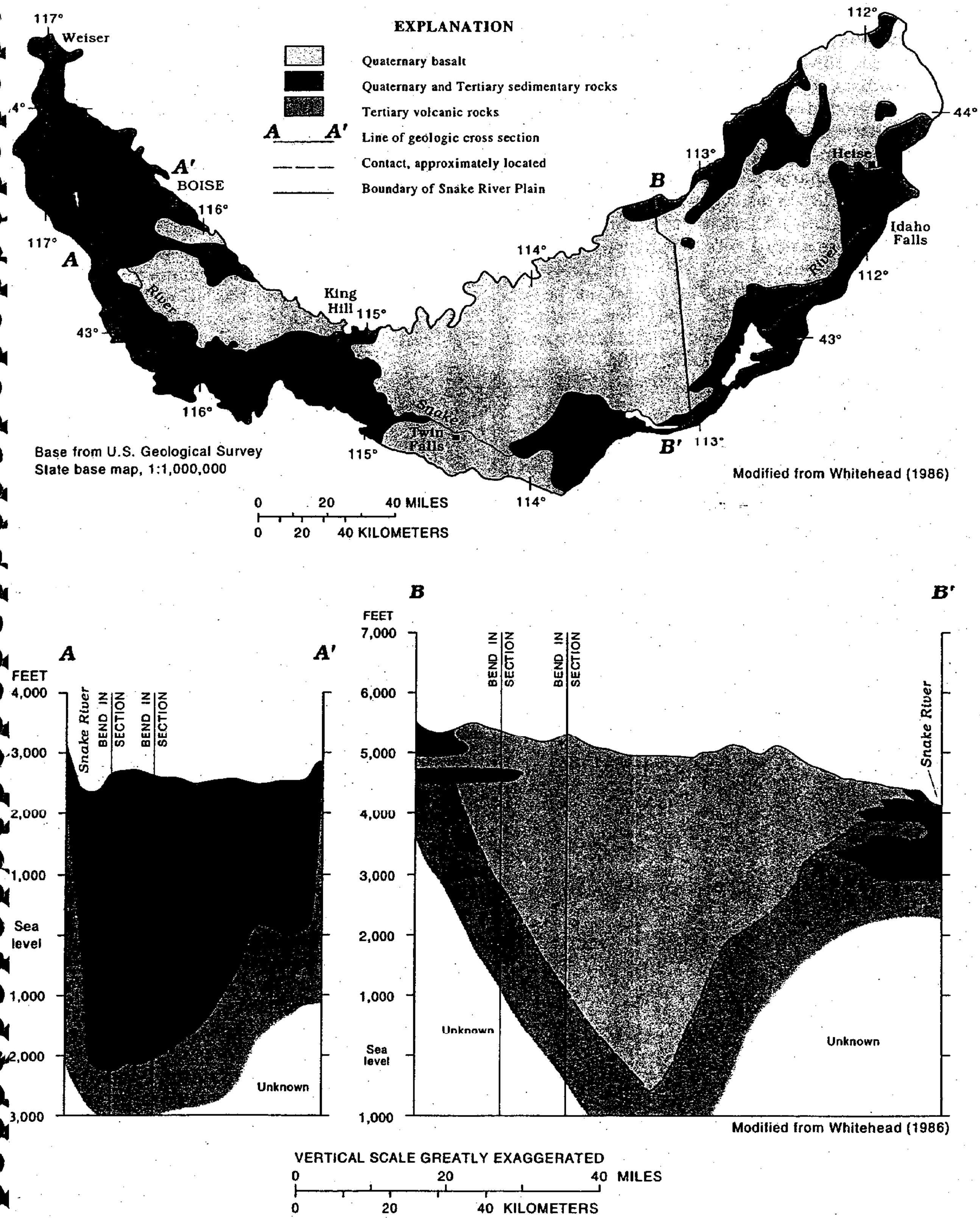


FIGURE 4.—Generalized geology of the Snake River Plain.

along the margins of the western plain increase vertical hydraulic connections. Newton (1991) estimated from specific-capacity data that hydraulic conductivity of sedimentary rocks in the western plain ranges from about 10 to 80 ft/d. Aquifer tests of 14 wells completed in sediments in the Boise River valley indicated transmissivities of 5,000 to 230,000 ft^2/d.

SOURCES OF WATER IN THE PLAIN

Sources of water to the Snake River Plain are (1) the Snake River; (2) water yield from tributary drainage basins, including water from foothill areas along the plain's boundaries; and (3) precipitation on the plain. Discussion of each source follows.

SNAKE RIVER

The Snake River is the main source of water to the plain and, in water year 1980, supplied almost 50 percent of the total inflow to both the eastern and western parts of the plain (table 6). Inflow to the eastern plain from the Snake River is measured near Heise (pl. 1, site 1); inflow to the western plain is measured at King Hill (pl. 1, site 13). Inflow to the western plain from the Snake River includes large quantities of ground water that discharge to the river from the eastern plain.

In water year 1980, almost 7.1 million acre-ft of water was diverted from the Snake River for irrigation on the plain. Diversions in calendar year 1980 are given in a report by Goodell (1988).

TRIBUTARY DRAINAGE BASINS

Kjelstrom (1986) determined mean annual water yield to the Snake River Plain from mountainous areas bordering the plain for water years 1934–80; results are summarized in table 7. Water yield to the plain, as used throughout this report, is the total of streamflow and ground-water discharge from tributary drainage basins. Water yield was adjusted for development, such as irrigation, upstream from the boundary of the plain. About 85 percent of the total water yield from tributary drainage basins in water year 1980 was measured streamflow. Frequency analyses of mean annual streamflow at gaging stations indicate probable ranges of water yield at selected recurrence intervals. The combined streamflow at stations measured in each basin was used in the frequency analyses.

Drainage from the headwaters of the Snake River to the eastern plain is measured at the gaging station near Heise (pl. 1, site 1). Henrys Fork is the largest

TABLE 6.—*Inflow to the Snake River Plain, water year 1980*

Source	Inflow (thousands of acre-feet) Eastern plain	Western plain
Snake River	[1]4,746	[2]6,784
Gaged tributary streams	3,874	6,357
Ground-water discharge from tributary drainage basins with gaged streams	949	67
Ungaged basins	759	455
Total	10,328	13,663

[1]Measured near Heise (site 1).
[2]Measured at King Hill (site 13).

tributary to the Snake River in the eastern plain. About 95 percent of the average water yield to the eastern plain in the lower Henrys Fork basin is measured near Ashton for streamflow in the Henrys Fork, near Squirrel for streamflow in the Falls River, and near St. Anthony for streamflow in the Teton River (pl. 1, sites 18, 19, and 20, respectively). The lowest combined annual mean discharge at the three stations was about 1.4 million acre-ft in 1934; the highest was about 3.0 million acre-ft in 1971. Henrys Fork near Ashton is regulated by two upstream reservoirs. Except for upstream irrigation diversions, streamflow in the Teton and Falls Rivers is unregulated.

Measured streamflow of Willow Creek near Ririe, Blackfoot River near Shelley, and Portneuf River at Pocatello (pl. 1, sites 23, 24, and 26, respectively) accounts for about 85 percent of the water yield to the eastern plain from tributary drainage basins between Henrys Fork and Neeley. Measured streamflow of Goose Creek above Trapper Creek near Oakley, Trapper Creek near Oakley, and Salmon Falls Creek near San Jacinto, Nev. (pl. 1, sites 29, 30, and 36, respectively), accounts for about 35 percent of water yield from tributary drainage basins between Neeley and Salmon Falls Creek.

Northern tributary drainage basins between Henrys Fork and Little Wood River do not discharge directly to the Snake River. Instead, within a few miles of the plain's boundary, all streamflow evaporates or percolates through highly permeable basalt and eventually recharges the ground-water system. Measured streamflow of the Little Lost River near Howe and Big Lost River below Mackay Reservoir (pl. 1, sites 39 and 40, respectively) accounts for about 25 percent of the water yield from northern tributary drainage basins. Almost 90 percent of the water yield to the plain from the Big and Little Wood River basins is measured streamflow

TABLE 7.—*Mean and selected statistical information for annual water yield and streamflow from mountainous areas bordering the Snake River Plain, water years 1934–80*

Source	Water yield (thousands of acre-feet): Mean annual, water years 1934–80: Total[1]	Mean annual, water years 1934–80: Measured streamflow	Annual mean, water year 1980: Measured streamflow	Number of stations measured	Streamflow for selected recurrence intervals as a percentage of mean annual discharge: Annual low streamflow: 50-year	Annual low streamflow: 10-year	Annual high streamflow: 10-year	Annual high streamflow: 50-year
Eastern Plain								
Headwaters of Snake River	4,964	4,953	4,741	1	67	79	129	146
Henrys Fork basin	2,333	2,226	2,218	3	67	78	121	134
Eastern tributary drainage basins	713	572	529	3	40	58	142	169
Southern tributary drainage basins	421	148	205	3	36	53	158	198
Northern tributary drainage basins	1,056	280	307	2	51	65	133	164
Big and Little Wood River basins	728	466	455	2	22	34	120	173
Total	10,215	8,645	8,455	14				
Percent of total					59	67	129	151
Western Plain								
Bruneau River basin	347	297	315	1	35	53	154	197
Owyhee River basin	690	664	616	1	17	33	188	274
Boise River basin	2,112	2,097	1,818	1	52	66	139	173
Malheur River basin	598	172	166	2	28	44	172	245
Payette River basin	2,695	2,381	2,367	1	48	59	138	162
Weiser River basin	779	764	761	1	26	50	146	160
Miscellaneous basins	173	20	23	2	9	21	227	424
Total	7,394	6,395	6,066	9				
Percent of total					41	55	149	190
Snake River Plain								
Total	17,609	15,040	14,521	23				
Percent of total					51	62	138	167

[1]Total is streamflow and basin ground-water discharge to the Snake River Plain.

of the Big Wood River below Magic Dam near Richfield, Little Wood River near Carey, and Silver Creek at Sportsman Access near Picabo (pl. 1, sites 41, 42, and 43, respectively).

In water year 1980, about 92 percent of the total streamflow from drainage basins tributary to the western Snake River Plain was measured at gaging stations. About 72 percent of the 92 percent was from basins north of the plain and was measured at gaging stations on the Boise River near Boise, Payette River near Horseshoe Bend, and Weiser River near Weiser (pl. 1, sites 51, 57, and 63, respectively).

The remaining 20 percent of the measured streamflow was from basins south and west of the Snake River and was measured at gaging stations on the Bruneau River near Hot Springs; Owyhee River below Owyhee Dam, Oreg.; Malheur River below Nevada Dam near Vale, Oreg. (pl. 1, sites 45, 47, and 56, respectively); and at diversions from the Owyhee and Malheur Rivers.

Ground-water discharge from drainage basins tributary to the Snake River Plain was determined in different ways, depending on the type of data available. Many previous studies referenced by Kjelstrom (1986) include estimates of ground-water discharge from one or more tributary drainage basins. Previous investigators generally used water-budget and specific-discharge analyses to estimate the ground-water discharge. Kjelstrom (1986) adjusted their estimates if longer periods of record were available or if changes in water-resource development were known. For other basins, water yield was correlated with yield from nearby basins and indexed to streamflow at gaging stations. If no data were available, regional regressions were used to estimate water yield. If streamflow from a basin was not gaged, water yield was not separated into streamflow and ground-water discharge.

PRECIPITATION ON THE PLAIN

Most precipitation on the plain during the summer is evapotranspired. During winter and early spring, rain and melting snow provide water in amounts sufficient for ground-water recharge; after soil-moisture deficiencies are satisfied, water percolates to the zone of saturation.

Recharge from precipitation varies areally across the plain. Where porous basalt is at or near land surface, water readily infiltrates; where soil cover is thick and where layers of fine-grained sediment or dense basalt are present, ground-water recharge is impeded. Fine-grained sediments intercalated with basalt, particularly near the margins of the eastern plain, impede vertical water movement and cause perched-water zones. Similar perched-water zones have been defined near Mountain Home, in the western plain. However, with time, some water from perched-water zones leaks through the fine-grained sediments and recharges the regional ground-water-flow system.

Basin water-budget analyses indicate that recharge from precipitation on the eastern plain averages about 0.08 ft/yr, a total of about 600,000 acre-ft, and on the western plain, about 0.03 ft/yr, a total of about 100,000 acre-ft.

TABLE 8.—*Instream storage facilities on the Snake River upstream from Weiser*

Storage facility	Storage capacity (thousands of acre-feet)	Year storage began
Jackson Lake	[1]847	1906
Palisades Reservoir	1,400	1956
American Falls Reservoir	1,700	1926
Lake Walcott	107	1906
Milner Lake	[2]28	1905
C.J. Strike Reservoir	250	1952

[1]Storage in 1980 was restricted to 300,000 acre-feet because of leaks in dam.
[2]Storage varies with discharge.

TABLE 9.—*Instream storage facilities greater than 50,000 acre-feet on tributary streams*

Storage facility	Stream	Storage capacity (thousands of acre-feet)	Year storage began
Henrys Lake	Henrys Fork	90	1922
Island Park Reservoir	Henrys Fork	127	1938
Ririe Reservoir	Willow Creek	100	1975
Blackfoot Reservoir	Blackfoot River	413	1910
Mud Lake	Camas Creek	62	1921
Oakley Reservoir	Goose Creek	74	1911
Salmon Falls Creek Reservoir	Salmon Falls Creek	182	1910
Magic Reservoir	Big Wood River	191	1909
Lake Owyhee	Owyhee River	1,122	1933
Anderson Ranch Reservoir	South Fork Boise River	464	1945
Arrowrock Reservoir	Boise River	286	1917
Lucky Peak Lake	Boise River	307	1954
Lake Lowell	Boise River	177	1908
Warm Springs Reservoir	Malheur River	190	1919
Beulah Reservoir	North Fork Malheur River	60	1935
Cascade Reservoir	North Fork Payette River	703	1947
Deadwood Reservoir	Deadwood River	160	1930
Crane Creek Reservoir	Crane Creek	60	1920

STREAMFLOW IN THE SNAKE RIVER

Streamflow in the Snake River is highly regulated across the plain. Regulations are mainly for irrigation supply and hydroelectric-power generation. Major instream storage facilities that affect streamflow in the Snake River are listed in downstream order in table 8. Tributary streams also are regulated (table 9). In addition to the storage facilities listed in table 9, numerous small (less than 50,000 acre-ft capacity) reservoirs have been built to regulate flow in tributary streams. Attempts to store water from the Snake River in offstream reservoirs have been unsuccessful because of ̣arge leakage losses. Wilson Lake Reservoir and Mur- augh Lake (pl. 1) are used mainly to regulate canal flow rather than to store water. Upstream storage de- reases streamflow in the Snake River near Heise dur- ng spring snowmelt; release from storage increases streamflow during the irrigation season (fig. 5).

Almost all surface water that leaves the eastern lain is measured at the gaging station at King Hill. Streamflow at King Hill is stable throughout the ear relative to streamflow at Heise because of the rge quantity of ground water that discharges to the river between Milner and King Hill (discussed in the ection "Streamflow Gains and Losses"). During 6 of he 72 years of record from 1911 to 1982, streamflow n the Snake River at King Hill exceeded 10 million cre-ft (fig. 6). Three of those 6 years were during the eriod from 1971 to 1976, when precipitation was bove normal.

The Snake River is the regional drain for the ground- ater-flow system, but the quantity of ground-water lischarge to the river from the western plain is insig- ificant relative to discharge from the eastern plain. .J. Strike Reservoir is the only major instream stor- ge facility on the western plain. Water stage in C.J. trike Reservoir generally is maintained at full storage apacity to maximize power generation and to mini- nize pumping lifts for irrigation diversions.

Streamflow in the Snake River at Weiser, where e river leaves the plain, exceeded 18 million acre-ft n 7 of the 72 years of record from 1911 to 1982 and as less than 9 million acre-ft for 6 years. Stream- ow was below average for 5 or more consecutive ears three times during that period. The period of owest streamflow was from 1931 to 1937, when the ean was 9.3 million acre-ft/yr. The period of highest ow for 5 or more consecutive years was from 1971 o 1976, when the mean was 17.5 million acre-ft/yr.

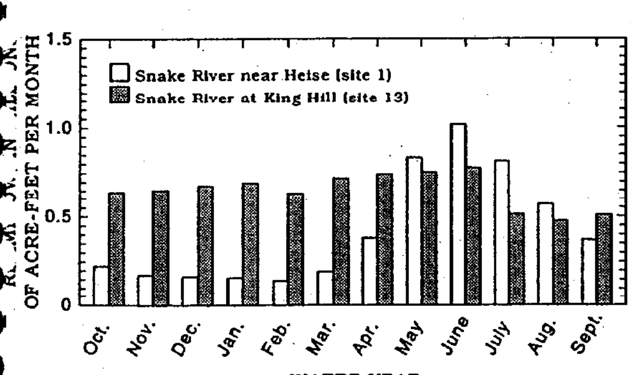


FIGURE 5.—Mean monthly streamflow in the Snake River near Heise (site 1) and King Hill (site 13), water years 1957–80.

STREAMFLOW GAINS AND LOSSES

A key to understanding ground-water and surface-water relations in the Snake River Plain is the analysis and quantification of Snake River streamflow gains from and losses to the ground-water-flow system. Streamflow gains and losses in water year 1980 were estimated by water-budget analysis for 15 reaches of the river. A water budget for each reach is summarized in table 10. Measurement and estimation errors had an unknown effect on the values obtained, but measured changes in ground-water levels and spring discharges support trends in streamflow gains and losses estimated by water-budget analysis. Irrigation-return flow and pumpage data collected during this study improved estimates of gains and losses for water year 1980. For the Blackfoot-to-Neeley reach and the four reaches from Milner to King Hill, total streamflow gains in the Snake River from ground-water discharge were estimated more accurately by measuring selected springs than by water-budget analysis. For other reaches, streamflow gains and losses were determined

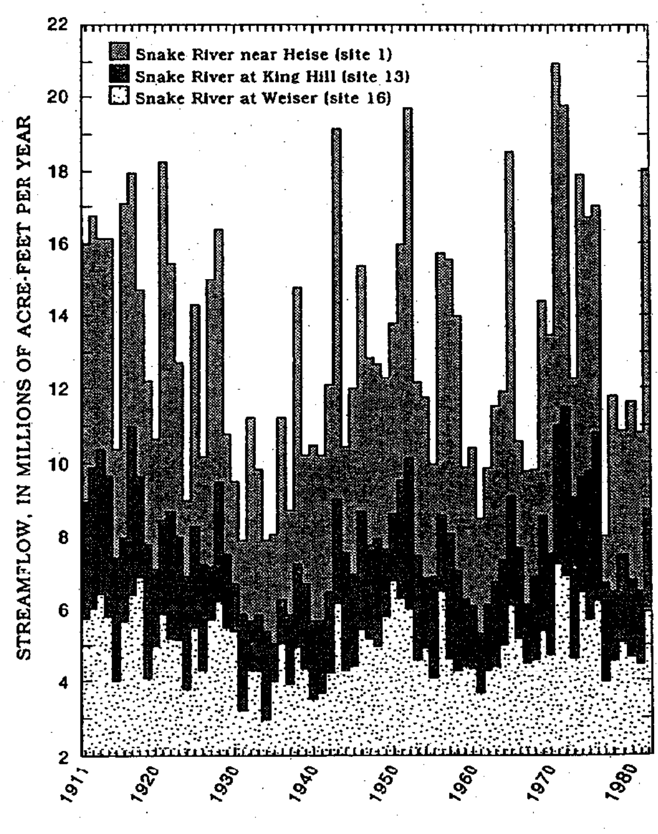


FIGURE 6.—Annual mean streamflow in the Snake River near Heise (site 1), King Hill (site 13), and Weiser (site 16), water years 1911–82.

TABLE 10.—*Water budgets for Snake River reaches, water year 1980*

[Values in thousands of acre-feet, unless otherwise noted; nr, near; —, no data available]

Reach (site Nos. shown on pl. 1)	Reach length (miles)	Inflow				Outflow					Residual	
		Snake River	Tributaries and drainages	Precipitation on reservoirs	Total	Snake River	Diversions	Evaporation	Change in reservoir storage	Total	Streamflow losses to ground water	Streamflow gains from ground water
Heise (1) to Lorenzo (2)	15.7	4,740	10	—	4,750	2,840	1,790	—	—	4,630	120	—
Lorenzo (2) to Lewisville (3)	22.6	2,840	1,810	—	4,650	4,370	620	—	—	4,990	—	340
Lewisville (3) to Shelley (4)	27.5	4,370	210	—	4,580	4,000	300	—	—	4,300	280	—
Shelley (4) to at Blackfoot (5)	23.5	4,000	60	—	4,060	3,100	850	—	—	3,950	110	—
At Blackfoot (5) to nr Blackfoot (6)	14.2	3,100	180	—	3,280	3,020	70	—	—	3,090	190	—
Near Blackfoot (6) to Neeley (7)	36.6	3,020	340	50	3,410	4,480	20	170	640	5,310	—	1,900
Neeley (7) to Minidoka (8)	40.0	4,480	120	20	4,610	[1]4,060	700	40	10	4,810	—	200
Minidoka (8) to Milner (9)	34.8	[1]4,060	120	—	4,230	1,290	2,770	10	—	4,070	110	—
Milner (9) to Kimberly (10)	21.5	1,290	10	—	1,300	1,510	—	—	—	1,510	—	210
Kimberly (10) to Buhl (11)	20.4	1,510	320	—	1,830	2,710	—	—	—	2,710	—	880
Buhl (11) to Hagerman (12)	24.3	2,710	270	—	2,980	5,590	40	—	—	5,630	—	2,650
Hagerman (12) to King Hill (13)	25.9	5,590	220	—	5,810	6,780	50	—	—	6,830	—	1,020
King Hill (13) to Murphy (14)	94.1	6,780	360	10	7,150	6,830	410	40	—	7,280	—	130
Murphy (14) to Nyssa (15)	67.3	6,830	1,460	—	8,290	8,370	180	10	—	8,560	—	270
Nyssa (15) to Weiser (16)	33.9	8,370	3,350	—	11,720	11,700	110	10	—	11,820	—	100

[1] Adjusted.

by the water-budget equation. Some reaches in the Snake River gain or lose water throughout the year; other reaches gain water during the irrigation season, when water levels in the underlying aquifer are higher than the water stage in the river, but lose water the rest of the year, when ground-water levels are lower than the water stage in the rivers.

In determining the accuracy of streamflow measurements, Rantz and others (1982, p. 182) found that if single streamflow measurements were made at a number of sites, the standard error would be ±2.2 percent. If a large number of streamflow measurements were made, two out of every three measurements could be expected to be within one standard error. Therefore, as a guide to the reliability of the estimated streamflow gains and losses during this study, 2 percent of the representative streamflow through each reach (streamflow at upstream or downstream gaging station, whichever was largest owing to gains, losses, diversions, and changes in storage) is shown in the graphs of gains and losses. If estimated gains and losses are less than or near 2 percent of the measured streamflow, they are assumed to be unreliable. However, water-budget errors still could be larger than this selected error band. The following sections are discussions of streamflow gains and losses in the Snake River between gaging stations located and listed on plate 1.

HEISE TO SHELLEY

Discharge records from gaging stations near Heise and Shelley (pl. 1, sites 1 and 4, respectively) make it possible to analyze streamflow gains and losses in the Snake River from Heise to Shelley from 1932 to 1980 (fig. 7). The apparent long-term changes in ground-water levels from 1932 to 1980 that are indicated by changes in streamflow gains and losses can be attributed to periods of above- and below-normal precipitation, respectively, and changes in irrigation practices.

The gaging station near Heise is upstream from most diversions, and annual streamflow is largely an indicator of long-term changes in precipitation. Hydrographs of streamflow gains and losses between Heise and Shelley were compared with annual mean streamflow near Heise (fig. 8). Changes in streamflow gains and losses are due to changes in precipitation and irrigation practices. Decreases in streamflow losses between Heise and Shelley from 1932 to the mid-1950's may be attributed to rising ground-water levels resulting from increases in recharge due to surface-water irrigation. Surface-water diversions for irrigation generally are larger when streamflow is high. From the early 1950's through 1964, both pumpage of ground water for irrigation and streamflow losses in the Snake River increased.

HEISE TO LORENZO

Owing to many years of irrigation, the Snake River has changed from a continually losing to a seasonally losing stream between Heise and Lorenzo (pl. 1, sites 1 and 2, respectively). Snake River streamflow at Lorenzo was measured initially from April to September 1924–27. Stearns and others (1938, p. 183) reported that during each month of that period, the Snake River between Heise and Lorenzo lost an average of 3.3 percent of the streamflow measured at Heise. A continuous-record streamflow-gaging station has been operated at Lorenzo since January 1978. Analysis for water years 1979–80 indicates that the Snake River gains or loses water in the reach from Heise to Lorenzo during different times of the year (fig. 9). For example, the river gained from May to October, or during most of the 1979 irrigation season (April-October), when recharge from part of the water applied for irrigation and canal leakage raised ground-water levels above river stage; the river lost during the nonirrigation season when ground-water levels were lower than the river stage. Streamflow

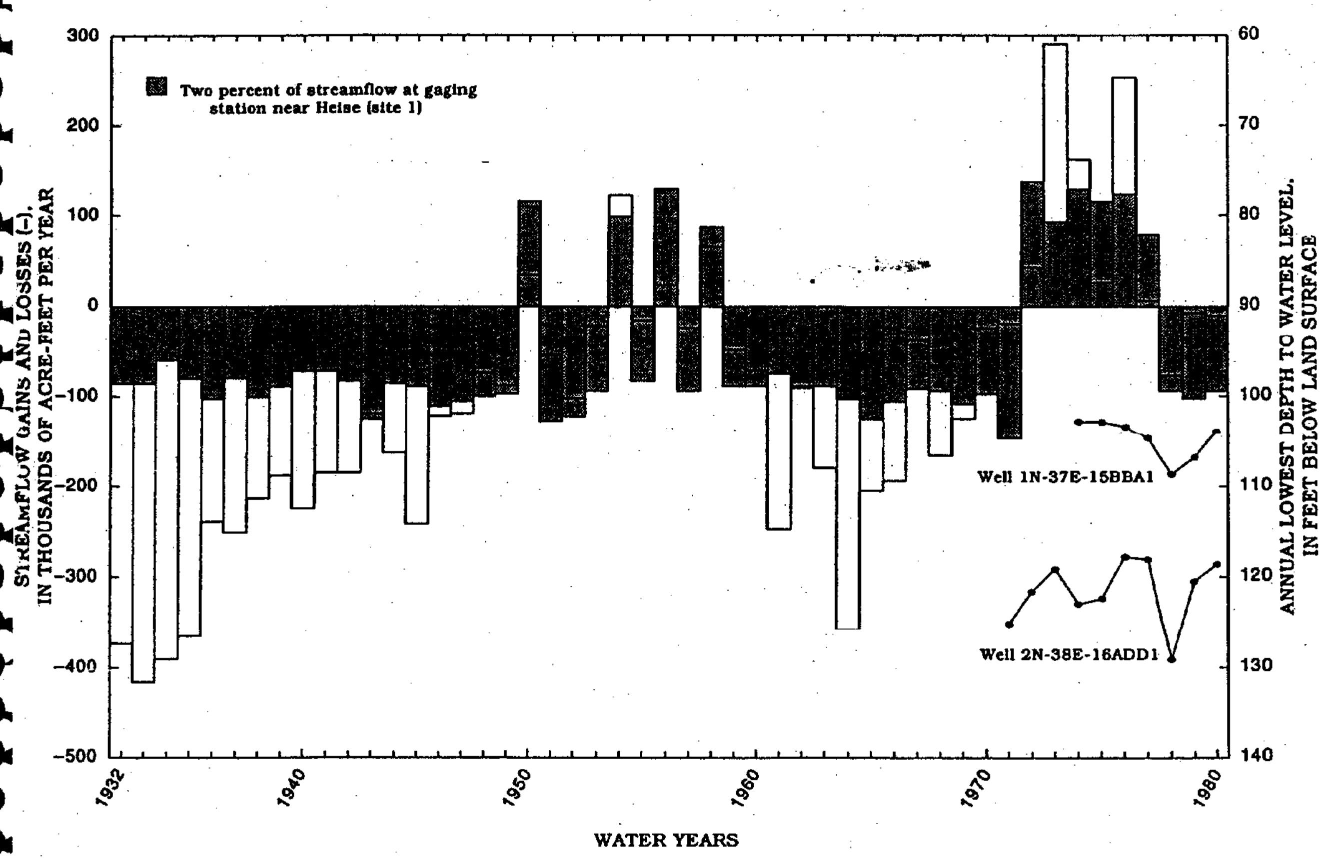


FIGURE 7.—Annual streamflow gains and losses in the Snake River between Heise (site 1) and Shelley (site 4), water years 1932–80, and water levels from periodic measurements in wells 2N-38E-16ADD1 and 1N-37E-15BBA1, water years 1971–80.

gains and losses in the reach correlate with water levels in well 4N-39E-16DAD1 (pl. 1, site W3), which is completed in Quaternary alluvium at a depth of 77 ft. Wells 4N-39E-26DAA1 and 3N-40E-8BAA1 (pl. 1, sites W2 and W1, respectively) are upgradient from well 4N-39E-16DAD1 and also are completed in alluvium. The relation between water levels in the three wells and the water stage in the Snake River at Lorenzo before (March 19, 1980) and during (July 22, 1980) the irrigation season is shown in figure 10. The gradient of the ground-water table was above the river stage on July 22 but was below the river stage on March 19. The rise in water levels in the three wells may be attributed to recharge from surface-water irrigation.

LORENZO TO LEWISVILLE

Between Lorenzo and Lewisville (pl. 1, sites 2 and 3, respectively), the Snake River gains from ground water throughout most years but gains more water during the irrigation season than during the nonirrigation season (fig. 11). Water levels in well 4N-38E-12BBB1 (pl. 1, site W4), which is completed in basalt of the Snake River Group, correlate directly with monthly streamflow gains in the reach.

LEWISVILLE TO SHELLEY

The Snake River generally loses to ground water between Lewisville and Shelley (pl. 1, sites 3 and 4, respectively); streamflow losses decrease as ground-water levels rise owing to recharge from canal seepage and percolation of irrigation water (fig. 12).

As ground-water levels decline at the end of an irrigation season, the ground-water-flow system can accept larger streamflow losses. Water levels in well 2N-38E-16ADD1 (pl. 1, site W5), completed in basalt at a depth of 225 ft and located a few miles east of the Snake River, correlate with monthly streamflow losses in the reach (fig. 12).

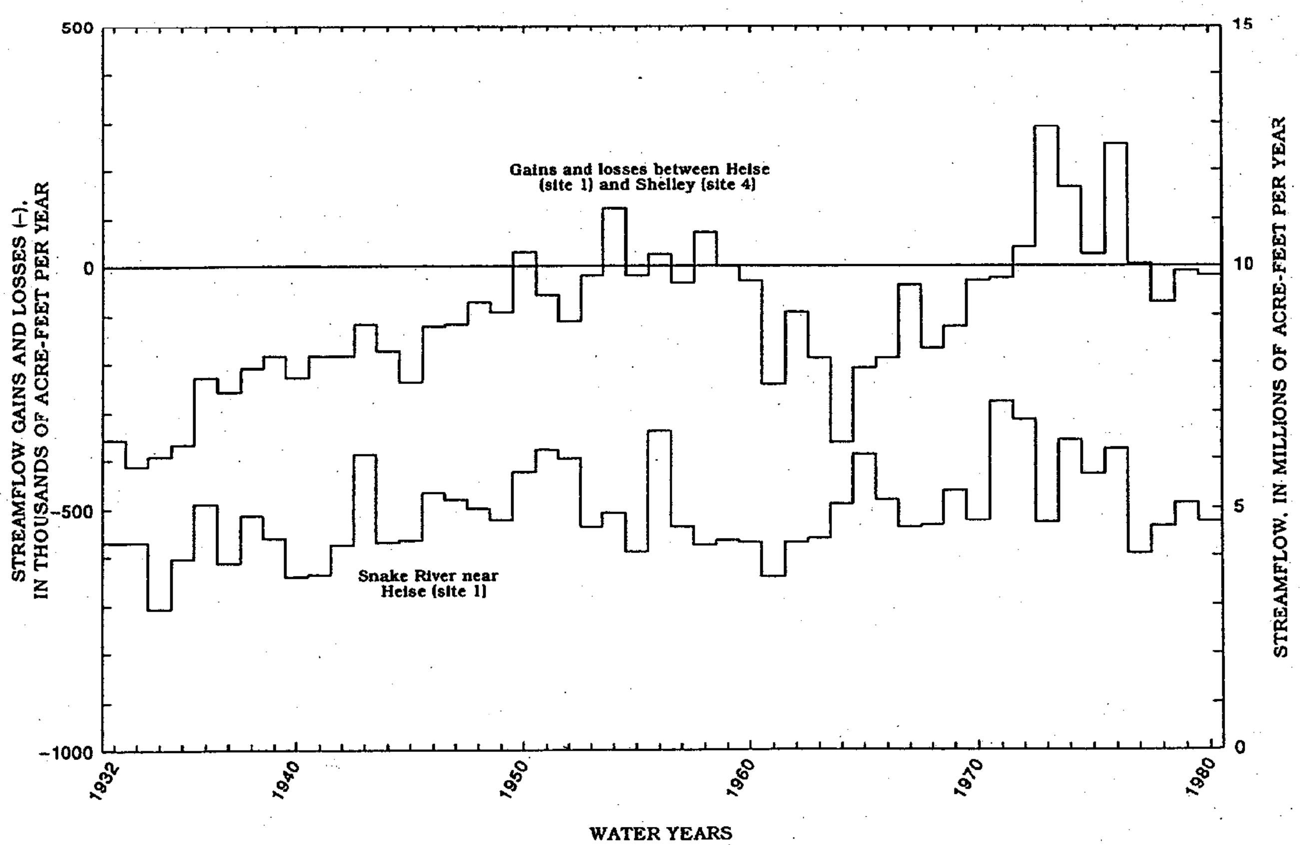


FIGURE 8.—Annual streamflow gains and losses in the Snake River between Heise (site 1) and Shelley (site 4), and annual mean streamflow near Heise, water years 1932–80.

In water year 1980, streamflow was about 90 percent of the mean (1911–80) and precipitation on the plain was above normal, so 1980 should represent average conditions.

SHELLEY TO NEAR BLACKFOOT

Annual streamflow losses in the Snake River between Shelley and near Blackfoot (pl. 1, sites 4 and 6, respectively) were estimated by water-budget analysis for the period 1932–80 (fig. 13). Streamflow losses apparently decreased from the 1940's to the early 1970's, a trend related to rising ground-water levels resulting from the use of surface water for irrigation. Stearns and others (1938, p. 187) estimated that average annual streamflow losses in this reach of the Snake River from 1915 to 1927 were about 200,000 acre-ft. The larger losses in the 1930's and 1970's probably were due to low ground-water levels. March water levels in well 1S-37E-36CDA1 (pl. 1, site W6) were high before 1975, then declined thereafter (fig. 13), which correlates with streamflow losses in the Snake River. Water levels in well 1S-37E-28AAA1 (pl. 1, site W8), which is completed in shallow sand and gravel, show the same trend as water levels in well 1S-37E-36CDA1.

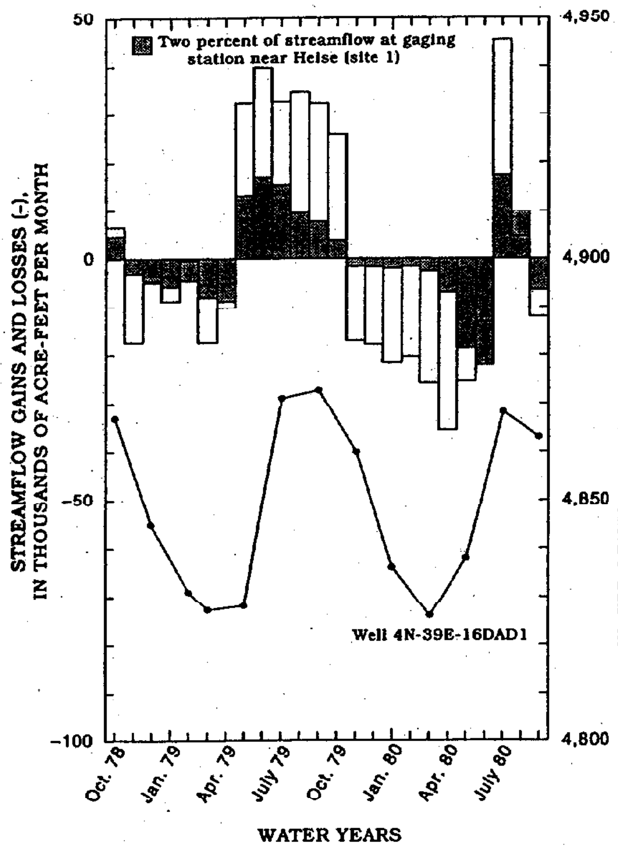
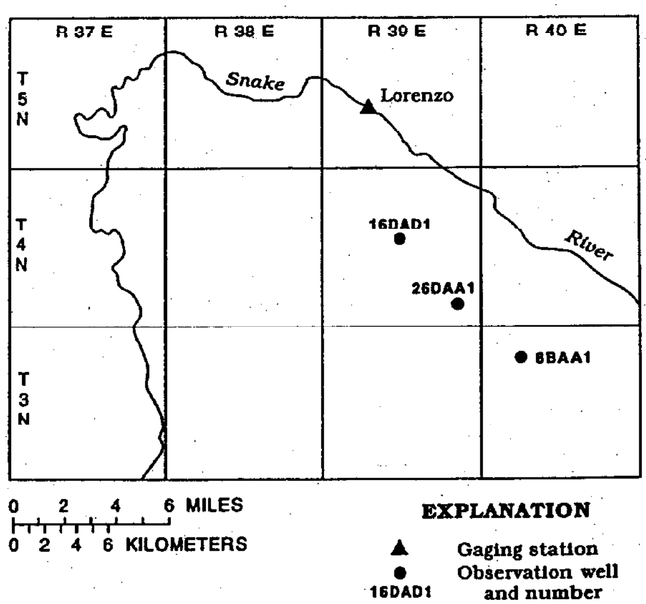


FIGURE 9.—Monthly streamflow gains and losses in the Snake River between Heise (site 1) and Lorenzo (site 2) and water levels from periodic measurements in well 4N-39E-16DAD1, water years 1979–80.

SHELLEY TO AT BLACKFOOT

During the irrigation season, ground-water levels rise and the Snake River gains from ground water between Shelley and at Blackfoot (pl. 1, sites 4 and 5, respectively); during the nonirrigation season, ground-water levels decline and the Snake River loses to ground water (fig. 14). Water levels in well 1N-37E-15BBA1 (pl. 1, site W7) correlate with monthly streamflow gains and losses. The well is



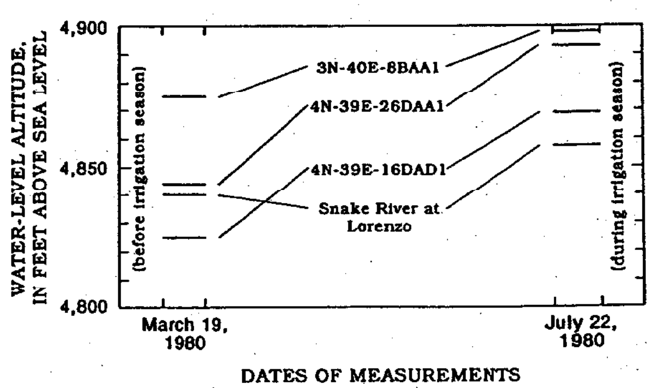


FIGURE 10.—Water levels in selected wells and water stage in the Snake River at Lorenzo (site 2) on March 19 and July 22, 1980.

open to basalt of the Snake River Group from 111 to 116 ft below land surface.

AT BLACKFOOT TO NEAR BLACKFOOT

Between gaging stations at Blackfoot and near Blackfoot (pl. 1, sites 5 and 6, respectively), the Snake River lost to ground water each month in water years 1979 and 1980 (fig. 15), even though springs discharge to the river about 3 mi upstream from the gaging station near Blackfoot. Estimated streamflow gain from ground water was about 116 ft^3/s on September 16, 1919; no other estimates have been made.

Discharge from springs along this reach minimizes streamflow loss. Discharge is greatest when ground-water levels in surface-water-irrigated areas are highest, at the end of an irrigation season; discharge is least when ground-water levels are lowest, just prior to the next irrigation season. Water levels in well 1S-37E-36CDA1 (pl. 1, site W6) generally correspond with seasonal changes in spring discharge during water years 1979–80. The well is completed in fractured volcanic rocks of the Salt Lake Formation of late Tertiary age at a depth of 415 ft.

NEAR BLACKFOOT TO NEELEY

The Snake River gained about 1.9 million acre-ft of ground water, largely from springs, between the gaging stations near Blackfoot and Neeley (pl. 1, sites 6 and 7, respectively) in water year 1980. Annual streamflow gains in the reach varied little during water years 1912–80 (fig. 16). The mean gain from ground water from 1912 to 1980 was 1.8 million acre-ft, or 2,540 ft^3/s; the standard deviation was 80,000 acre-ft, or 110 ft^3/s.

Ground-water discharge in the area inundated by American Falls Reservoir since 1926 was estimated in 1977 when the reservoir was drawn down for dam

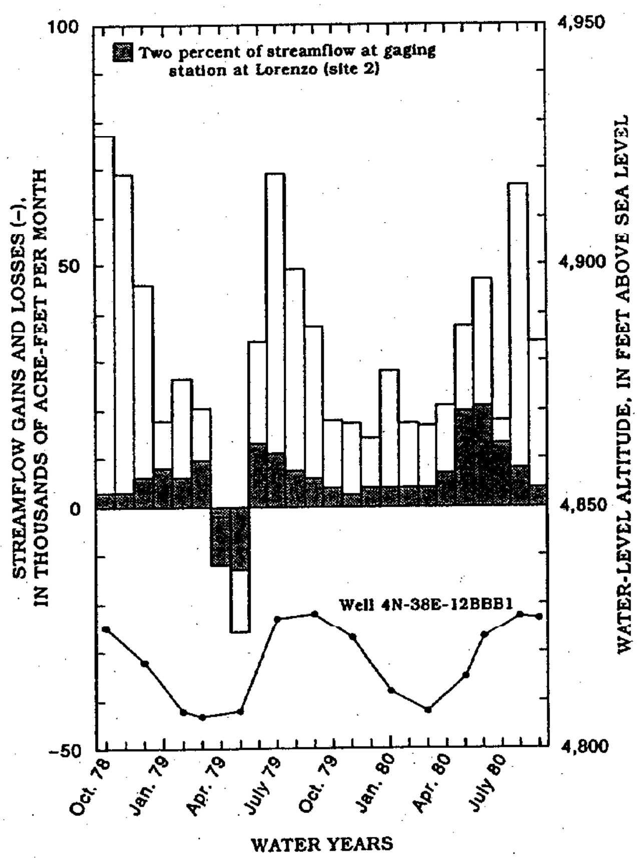


FIGURE 11.—Monthly streamflow gains and losses in the Snake River between Lorenzo (site 2) and Lewisville (site 3) and water levels from periodic measurements in well 4N-38E-12BBB1, water years 1979–80.

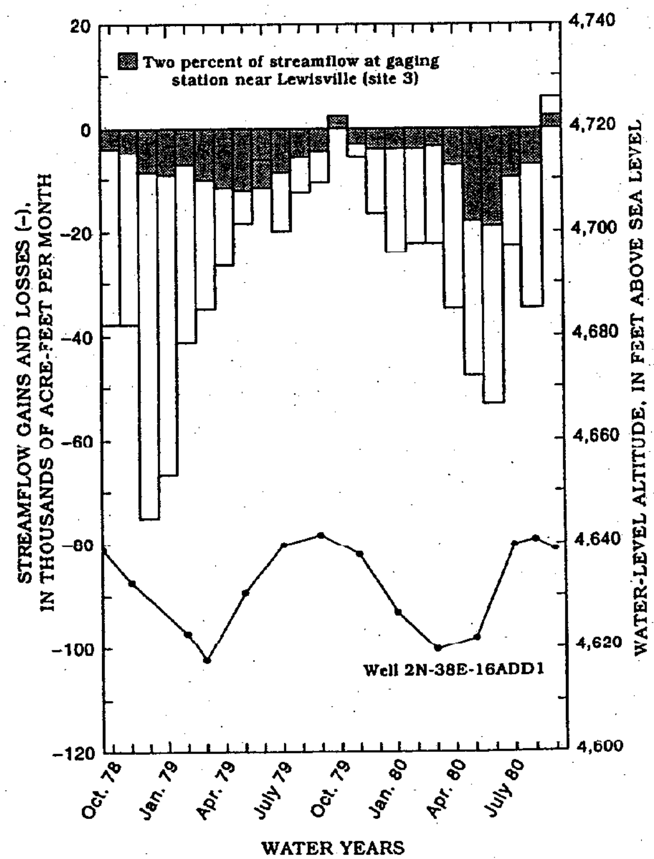


FIGURE 12.—Monthly streamflow gains and losses in the Snake River between Lewisville (site 3) and Shelley (site 4) and water levels from periodic measurements in well 2N-38E-16ADD1, water years 1979–80.

reconstruction. At that time, streamflow measurements of the Snake and Portneuf Rivers were made upstream and downstream from major springs (fig. 17). Total streamflow gain from ground water in the Blackfoot-to-Neeley reach on September 8 and 28, 1977, was estimated to be 2,560 and 2,570 ft^3/s, respectively. Surface-water inflow to the Snake River was about 50 ft^3/s on both days. The ground-water discharge estimated in September 1977 was almost equal to the average ground-water discharge estimated from 1912 to 1980.

The first record of large springs in the American Falls Reservoir area was made in 1830 by Captain Bonneville, who was seeking travel routes to the Oregon coast. The volume of discharge from the springs was first estimated in 1902 and 1905 by measuring streamflow in the Snake River upstream and downstream from the springs. The differences between upstream and downstream measurements were 2,000 and 1,960 ft^3/s. A more reliable estimation of discharge from the springs was made in August 1908 when, for 11 consecutive days, streamflow in the Snake River near Blackfoot and at Neeley was measured. The average difference in streamflow was adjusted for estimated surface-water inflow and evapotranspiration losses in wetlands near the mouth of the Portneuf River. Ground-water discharge to the reach in August 1908 was estimated to be about 2,000 ft^3/s.

Ground-water discharge to the natural channel of the Portneuf River is about 65 percent of the total ground-water discharge to the Blackfoot-to-Neeley reach. Historical increases in ground-water discharge to the Portneuf River and the Blackfoot-to-Neeley reach of the Snake River may be related partly to completion of the Blackfoot Reservoir in 1910. Ground-water discharge increased after 1910 when water from the reservoir was used to irrigate terraces north and east of several large springs that discharge to the Portneuf and Snake Rivers. On the basis of four streamflow measurements and daily gage-height readings from July 30 to September 17, 1910, Meinzer (1927, p. 51) reported that streamflow from the Portneuf River entering the Snake River ranged from 1,440 to 1,700 ft^3/s. Meinzer concluded that ground-water discharge to the Portneuf River at that time was about 1,400 ft^3/s. Streamflow measurements of the Portneuf River at Pocatello and upstream from Bannock Creek were made on September 9 and 17, 1977. After these measurements were adjusted for a measured diversion and estimated surface-water inflow, the average difference between outflow (measured at the downstream gage) and inflow was 1,650 ft^3/s (assumed to be ground-water discharge). The increase in ground-water discharge to the Portneuf River from 1910 to 1977 (1,650–1,400=250 ft^3/s) was about one-half of the increase in ground-water discharge to the Blackfoot-to-Neeley reach. The total increase was about 540 ft^3/s (mean gain of 2,540 ft^3/s from 1912 to 1980 minus the measured gain in 1908 of 2,000 ft^3/s=540 ft^3/s). Apparently,

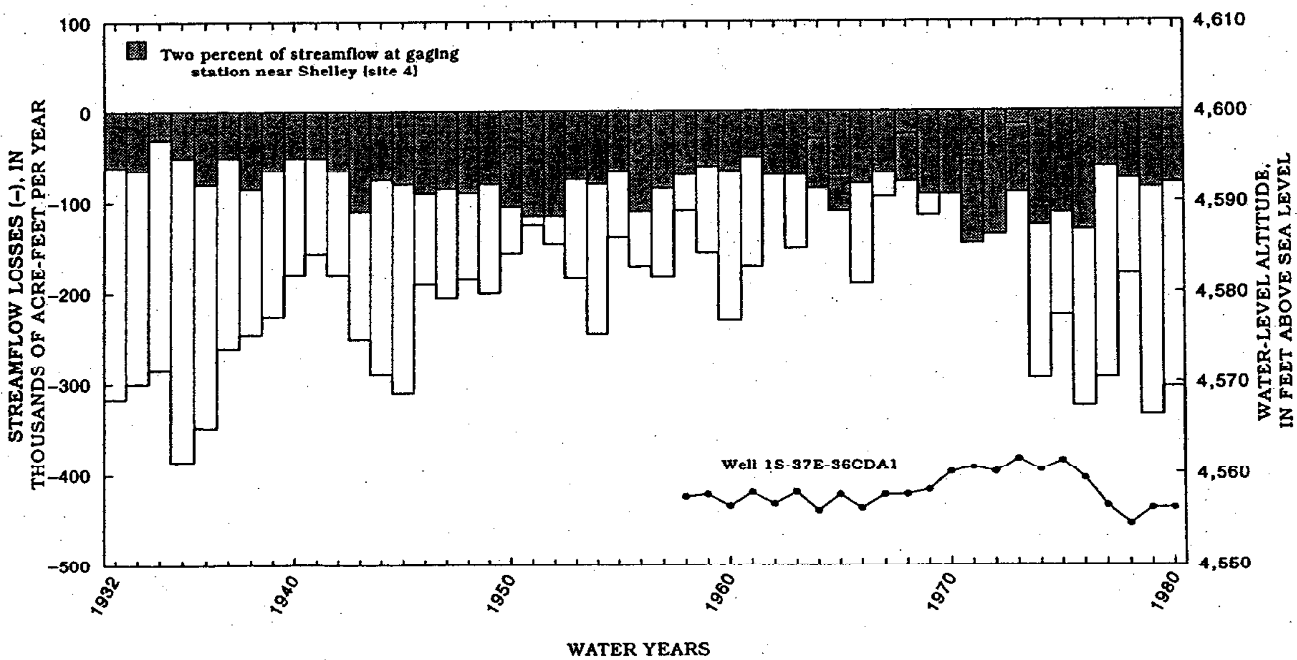


FIGURE 13.—Annual streamflow losses in the Snake River between Shelley (site 4) and near Blackfoot (site 6), water years 1932–80, and water levels from periodic measurements in well 1S-37E-36CDA1, water years 1958–80.

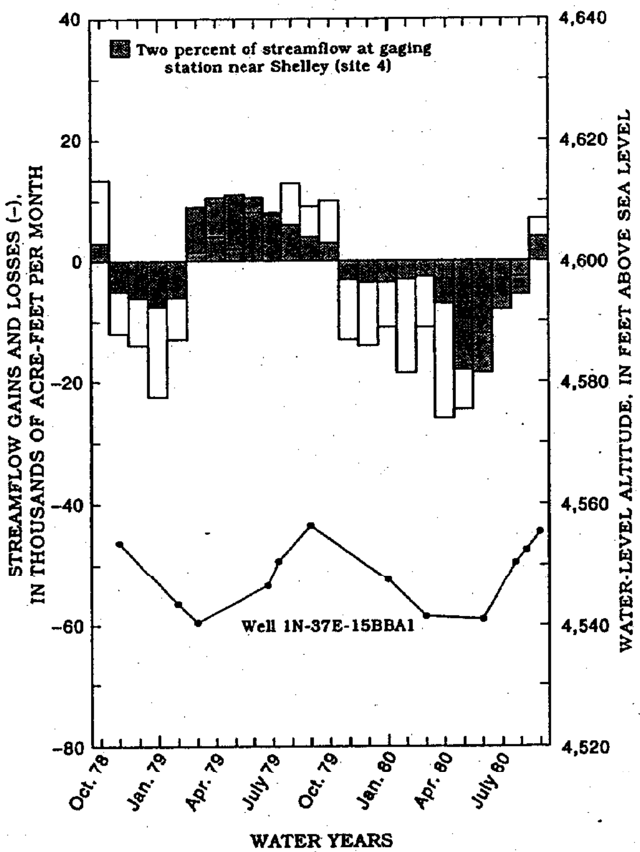


FIGURE 14.—Monthly streamflow gains and losses in the Snake River between Shelley (site 4) and at Blackfoot (site 5) and water levels from periodic measurements in well 1N-37E-15BBA1, water years 1979–80.

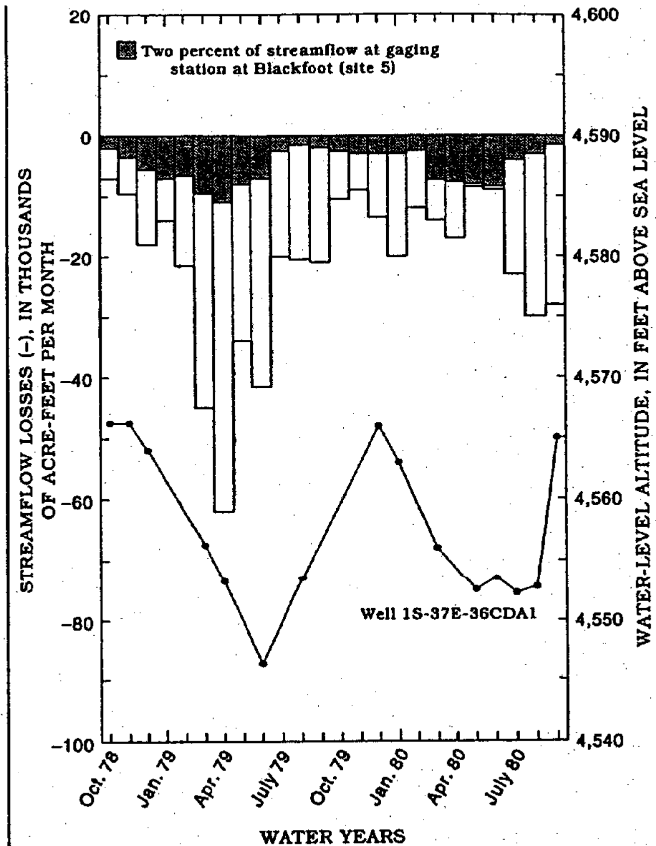


FIGURE 15.—Monthly streamflow losses in the Snake River between at Blackfoot (site 5) and near Blackfoot (site 6) and water levels from periodic measurements in well 1S-37E-36CDA1, water years 1979–80.

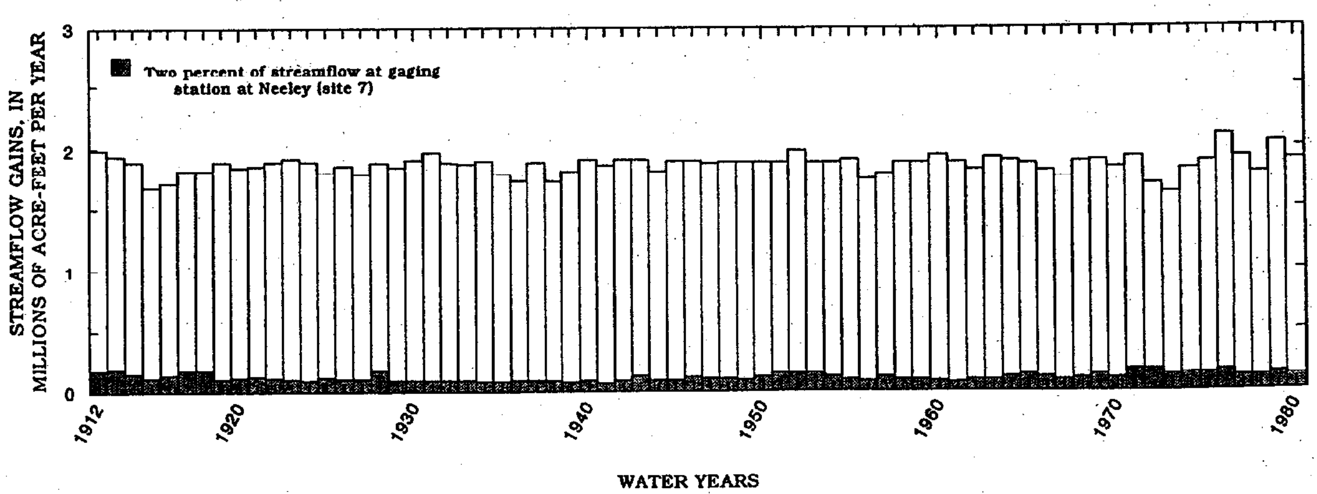


FIGURE 16.—Annual streamflow gains in the Snake River between near Blackfoot (site 6) and Neeley (site 7), water years 1912–80.

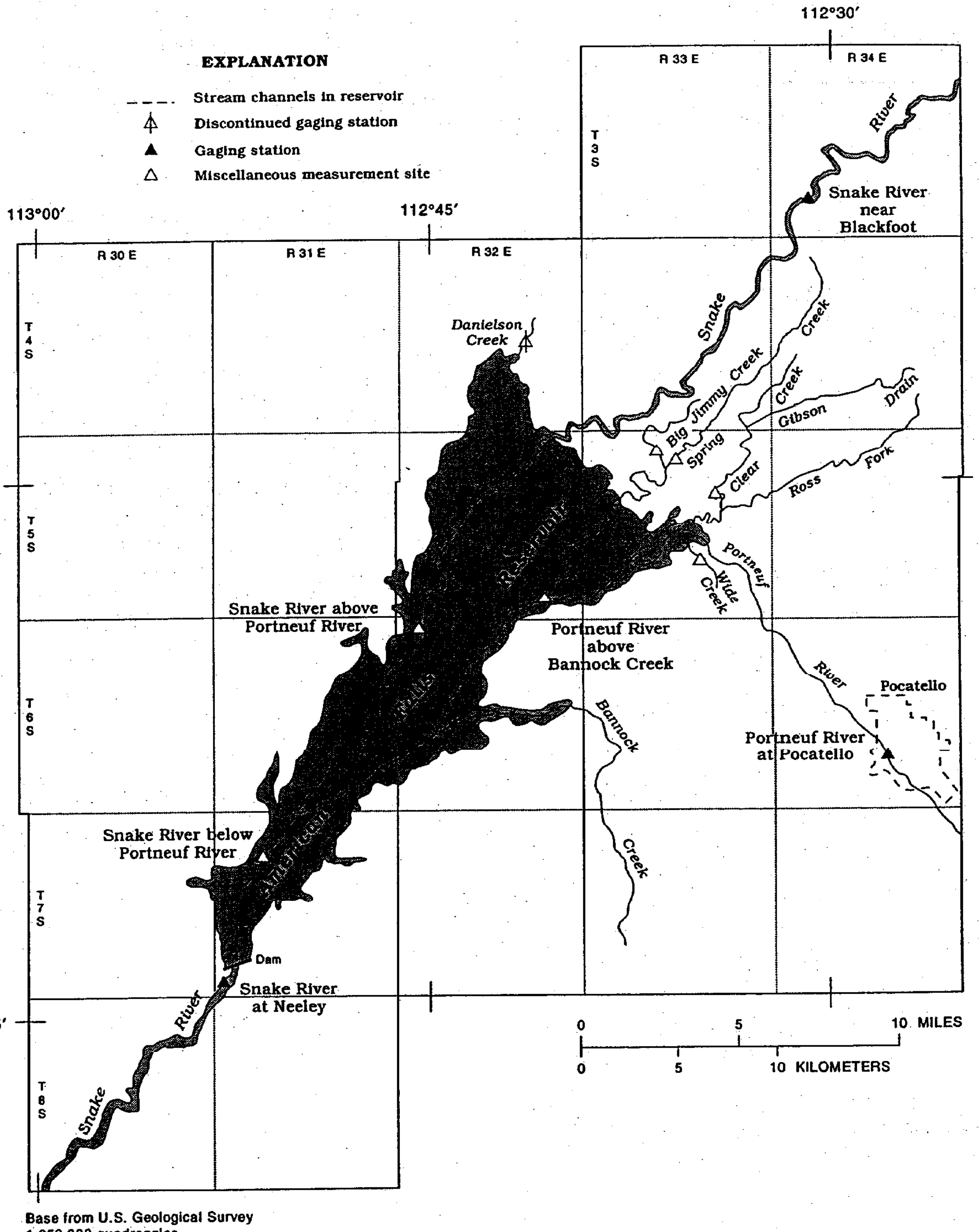


FIGURE 17.—Measurement sites used in analysis of spring discharge to American Falls Reservoir.

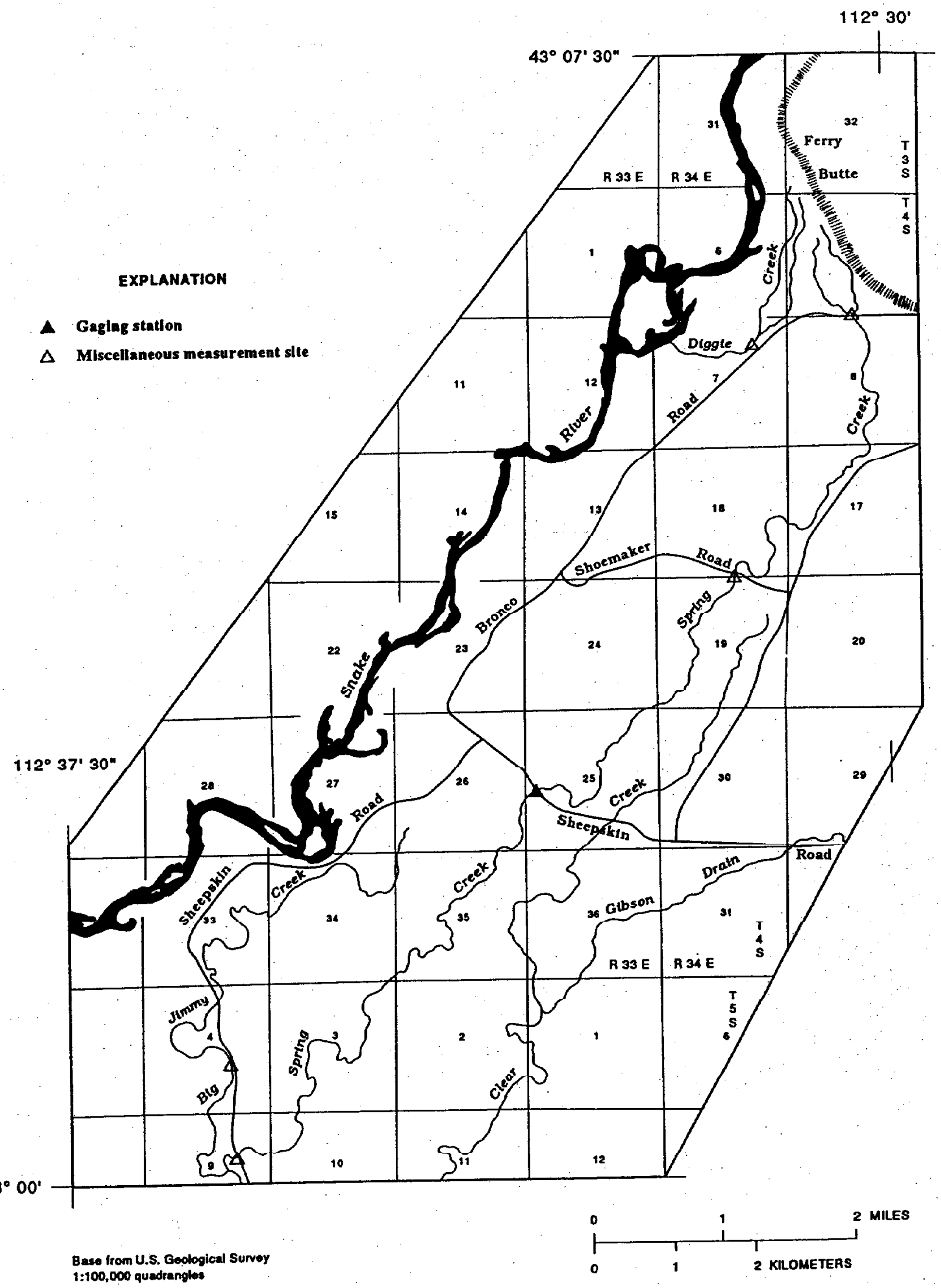


FIGURE 19.—Measurement sites on Spring Creek and on nearby spring-fed creeks.

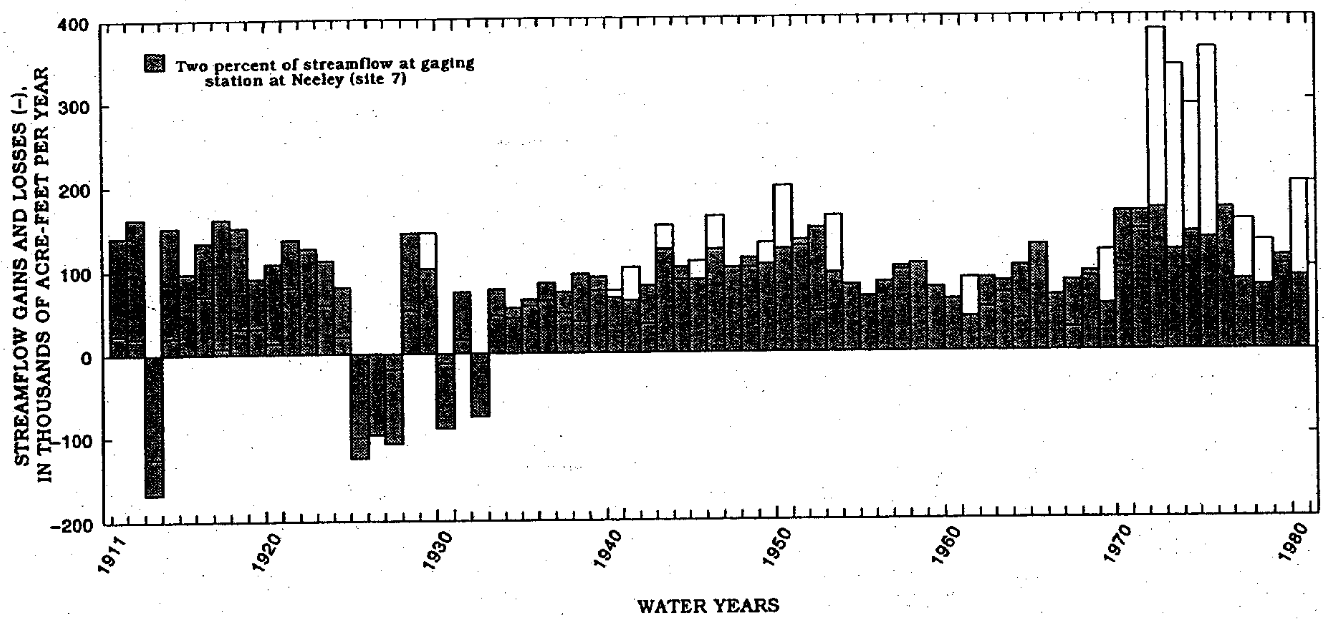


FIGURE 22.—Annual streamflow gains and losses in the Snake River between Neeley (site 7) and Minidoka (site 8), water years 1911–80.

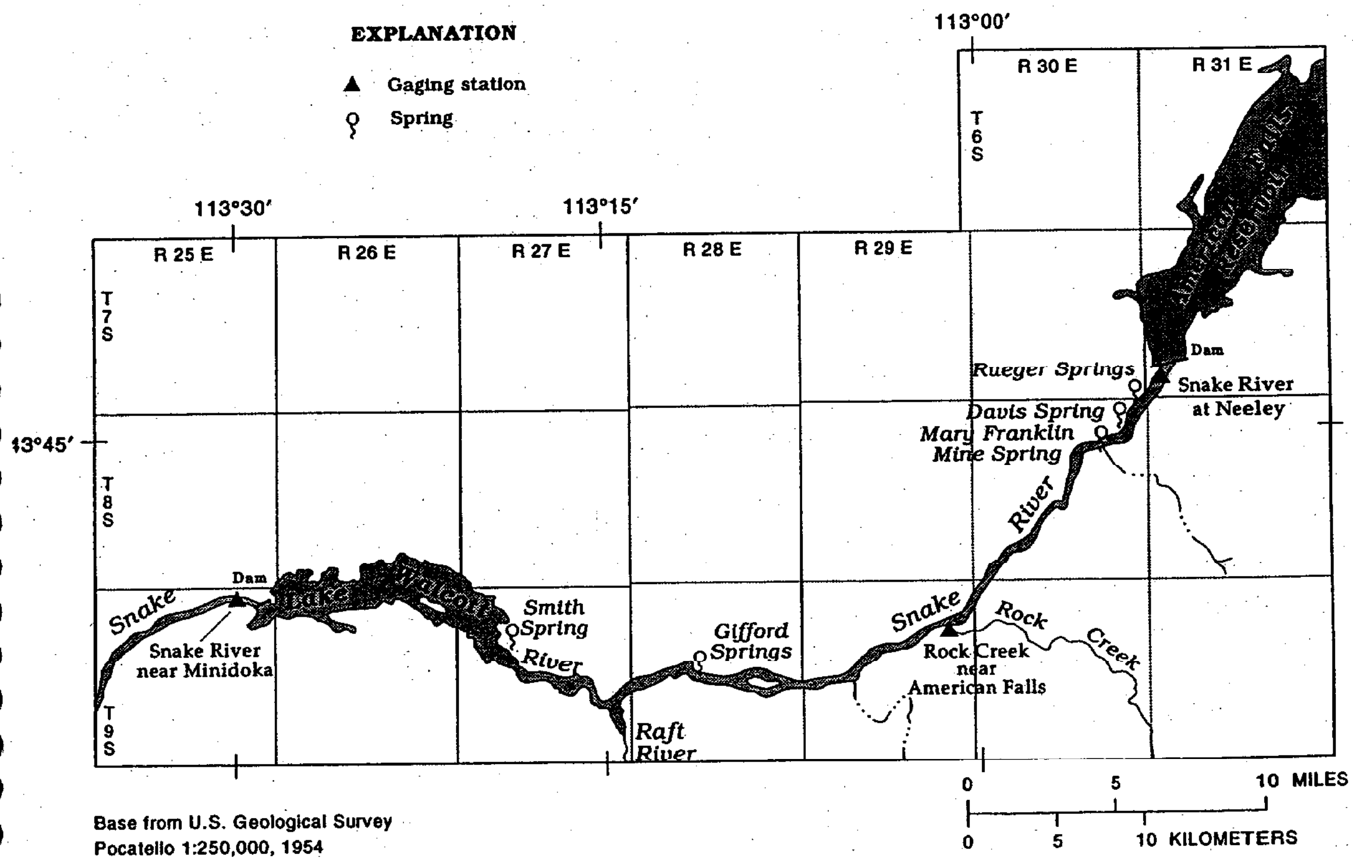


FIGURE 23.—Locations of springs discharging to the Snake River between Neeley (site 7) and Minidoka (site 8).

MILNER TO KIMBERLY

Between Milner and Kimberly (pl. 1, sites 9 and 10, respectively), the Snake River gained about 210,000 acre-ft from ground water in water year 1980, largely as seepage from south of the river. Estimated discharge from north-side springs was about 20,000 acre-ft. Average annual seepage from the south side from 1951 to 1980 was about 180,000 acre-ft.

Monthly total streamflow gains in this reach in water year 1980 are shown in figure 28. Because most of the gain is from the south side of the Snake River, it appears that the seasonal change in south-side seepage, like the seasonal change in north-side spring discharge (table 11), is influenced largely by irrigation.

KIMBERLY TO BUHL

The Snake River gained about 880,000 acre-ft from ground water between Kimberly and Buhl (pl. 1, sites 10 and 11, respectively) in water year 1980; about 810,000 acre-ft was from the north side. The relation between monthly total streamflow gains estimated from water-budget analysis and north-side gains estimated from measured spring discharge is shown in figure 29. The difference, assumed to be south-side gain, appears to be greater during the irrigation season. Average annual south-side gain from 1951 to 1980 was 80,000 acre-ft.

BUHL TO HAGERMAN

The Snake River gained about 2,650,000 acre-ft from ground water between Buhl and Hagerman (pl. 1, sites 11 and 12, respectively) in water year 1980. On the basis of measured spring discharge, about 2,510,000 acre-ft was estimated to be from the north side. The relation between monthly streamflow gains estimated from water-budget analysis and north-side gains estimated from measured spring discharge is shown in figure 30. North-side spring discharge is typically greatest in October and least in the spring.

Water-level trends in well 8S-14E-16CBB1 (pl. 1, site W18) correlate with seasonal trends in north-side spring discharge (fig. 31). The well is completed in basalt of the Snake River Group at a depth of 53 ft.

If south-side gain is the difference between total gain estimated from water-budget analysis and north-side gain estimated on the basis of spring-discharge measurements, south-side gain is highest in March

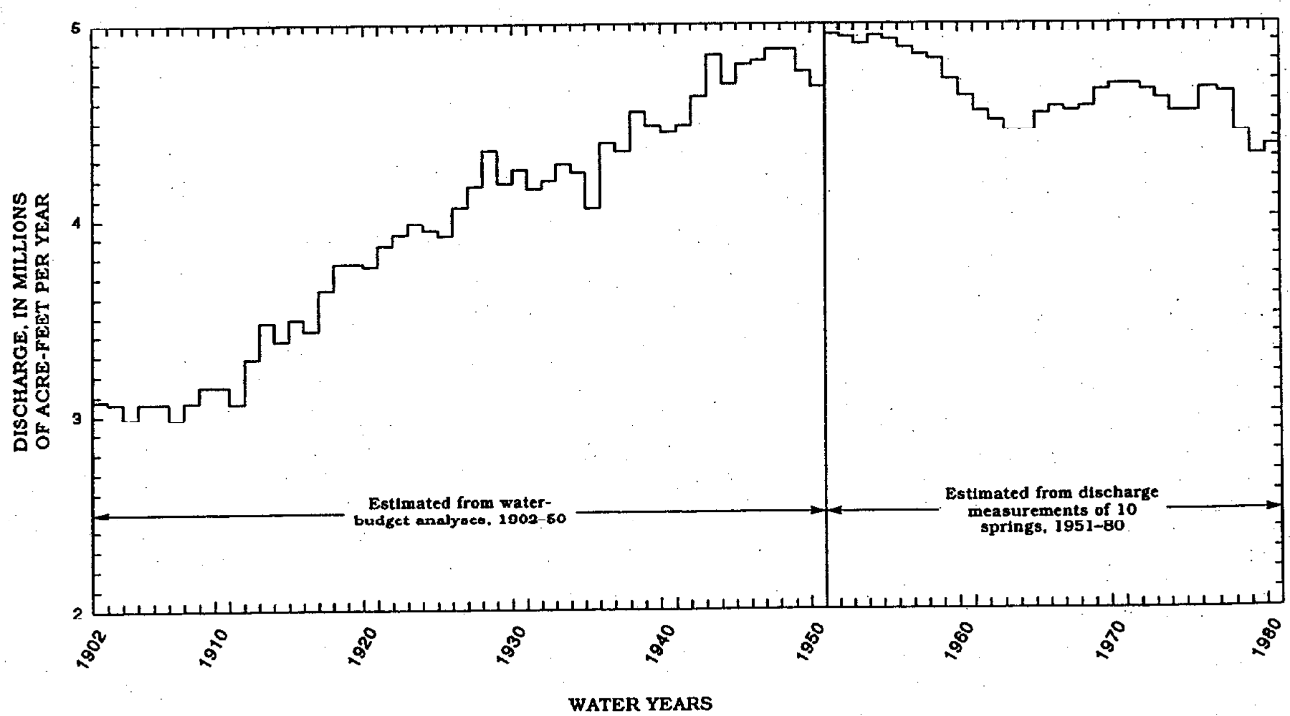


FIGURE 27.—Annual ground-water discharge from the north side of the Snake River between Milner (site 9) and King Hill (site 13), water years 1902–80.

and least in July. The water level in well 9S-13E-20CCD1 (pl. 1, site W19) south of the Snake River, completed in Idavada Volcanics of Tertiary age at a depth of 790 ft, is also highest in March and lowest in July (fig. 32). Estimated average annual south-side gain from 1951 to 1980 was 110,000 acre-ft.

HAGERMAN TO KING HILL

The Snake River gained about 1,020,000 acre-ft from ground water between Hagerman and King Hill (pl. 1, sites 12 and 13, respectively) in water year 1980. Most of the gain was from spring discharge along the north side. The relation between monthly streamflow gains estimated from water-budget analysis and north-side gains estimated from measured spring discharge is shown in figure 33.

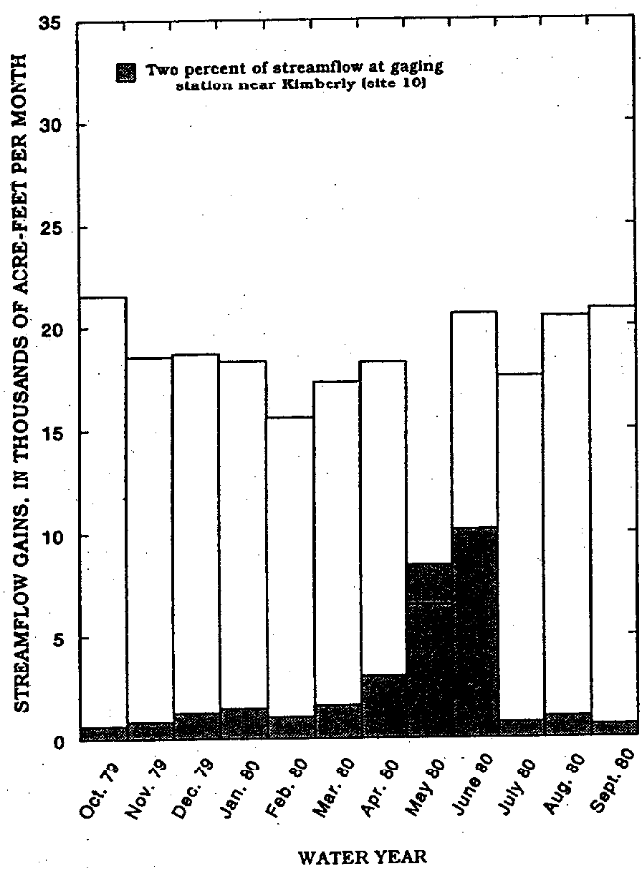


FIGURE 28.—Monthly total streamflow gains in the Snake River between Milner (site 9) and Kimberly (site 10), water year 1980.

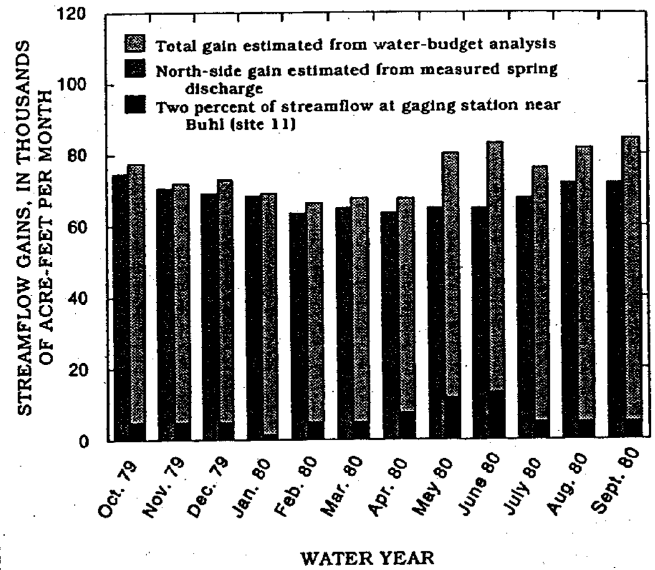


FIGURE 29.—Monthly total streamflow gains in the Snake River between Kimberly (site 10) and Buhl (site 11) estimated from water-budget analysis, and north-side gains estimated from measured spring discharge, water year 1980.

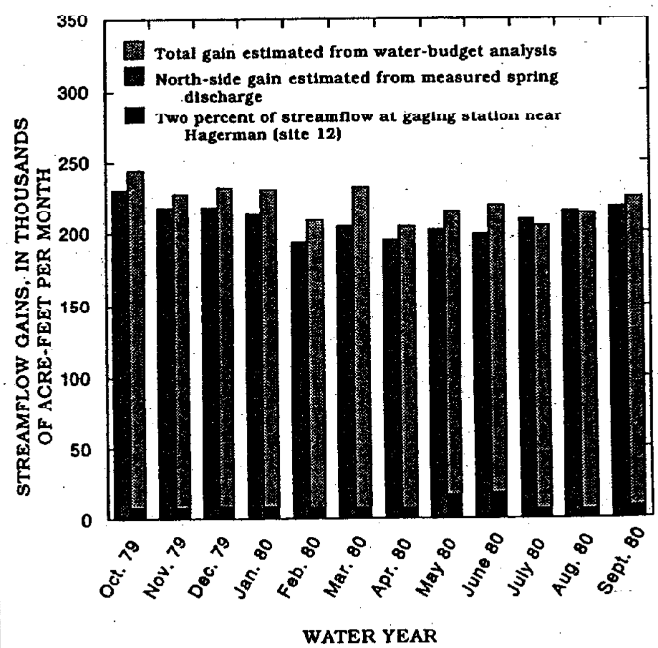


FIGURE 30.—Monthly total streamflow gains in the Snake River between Buhl (site 11) and Hagerman (site 12) estimated from water-budget analysis, and north-side gains estimated from measured spring discharge, water year 1980.

KING HILL TO MURPHY

The Snake River gained about 130,000 acre-ft from ground water between King Hill and Murphy (pl. 1, sites 13 and 14, respectively) in water year 1980. Estimates of gains downstream from King Hill generally were less reliable than estimates of gains upstream because diversions downstream from King Hill were not measured and had to be estimated. To compensate for estimation errors, average monthly gains were computed for water years 1975–80 (fig. 34). Although gains were often less than 2 percent of streamflow, all water years from 1944 to 1980 show streamflow gains from ground water (fig. 35).

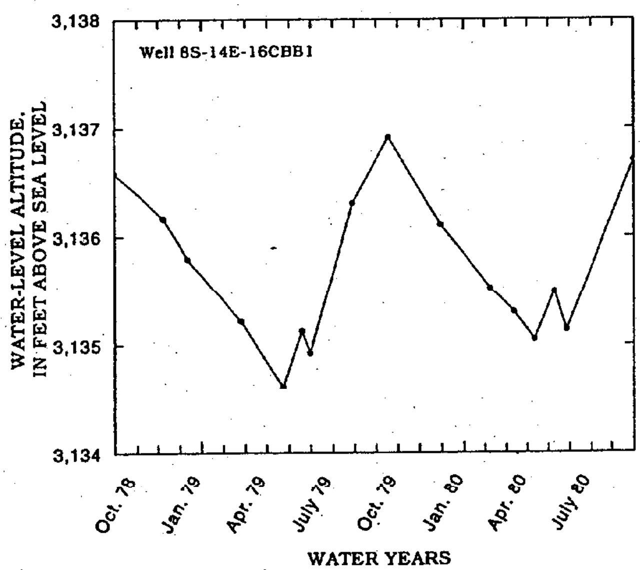


FIGURE 31.—Water-level altitude from periodic measurements in well 8S-14E-16CBB1, water years 1979–80.

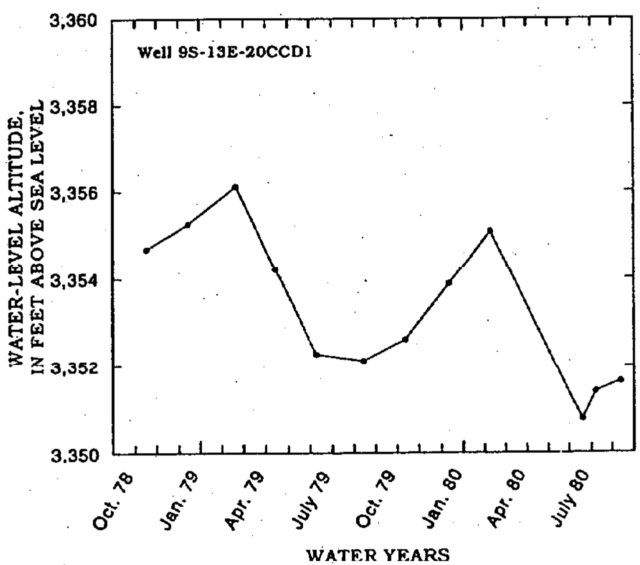


FIGURE 32.—Water-level altitude from periodic measurements in well 9S-13E-20CCD1, water years 1979–80.

MURPHY TO NYSSA

The Snake River gained about 270,000 acre-ft from ground water between Murphy and Nyssa (pl. 1, sites 14 and 15, respectively) in water year 1980. Because ground-water discharge is a small part of streamflow and estimates are subject to variations caused by measurement or estimation errors, average annual water budgets were determined for water years 1975–79 to evaluate the 1980 gain estimate. Gains in this reach from 1975 to 1980 averaged about 330,000 acre-ft.

Monthly water budgets for water year 1980 (fig. 36) indicate that between Murphy and Nyssa, the Snake River gains water throughout the year; however, in certain months, the estimated gains may be questionable because they are less than the selected error band, 2 percent of streamflow. Part of the monthly variation in gains may be due to errors in estimates of pumping directly from the river, which is a variable in the water-budget analysis.

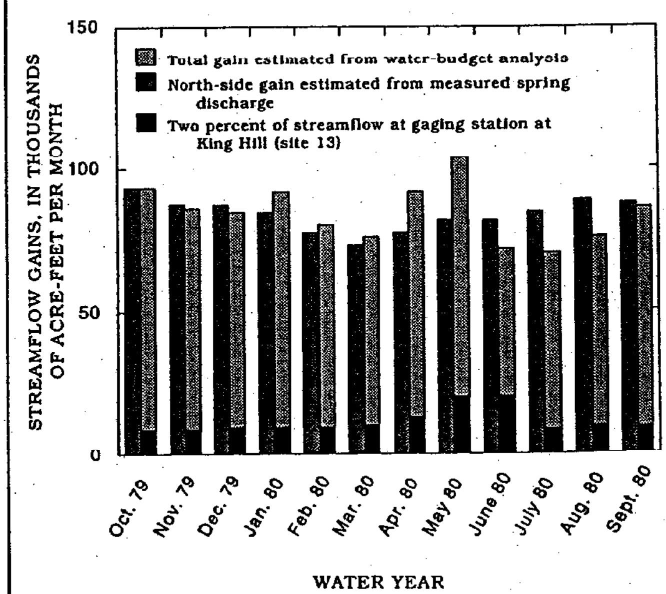


FIGURE 33.—Monthly streamflow gains in the Snake River between Hagerman (site 12) and King Hill (site 13) estimated from water-budget analysis, and north-side gains estimated from measured spring discharge, water year 1980.

NYSSA TO WEISER

Monthly water budgets for water year 1980 indicate that the Snake River between Nyssa and Weiser (pl. 1, sites 15 and 16, respectively) gains from ground water during the irrigation season and may lose to ground water during the nonirrigation season (fig. 37). Most of the estimated streamflow gains or losses are within 2 percent of measured streamflow; therefore, to evaluate the estimates, average monthly water budgets were estimated for water years 1975–79. The average monthly streamflow gains during the mid- and late-irrigation season (June-October) are about 30,000 acre-ft (fig. 38). Average annual ground-water discharge to the Snake River from 1975 to 1980 was estimated to be about 125,000 acre-ft. In 1980, water levels in well 8N-4W-33ACA1 (pl. 1, site W25) began to rise in April at the start of the irrigation season and began to decline in September at the end of the irrigation season (fig. 37). The well, just south of the Payette River and 4 mi east of the Snake River, is completed in alluvium. Water levels in the well are assumed to be indicative of the

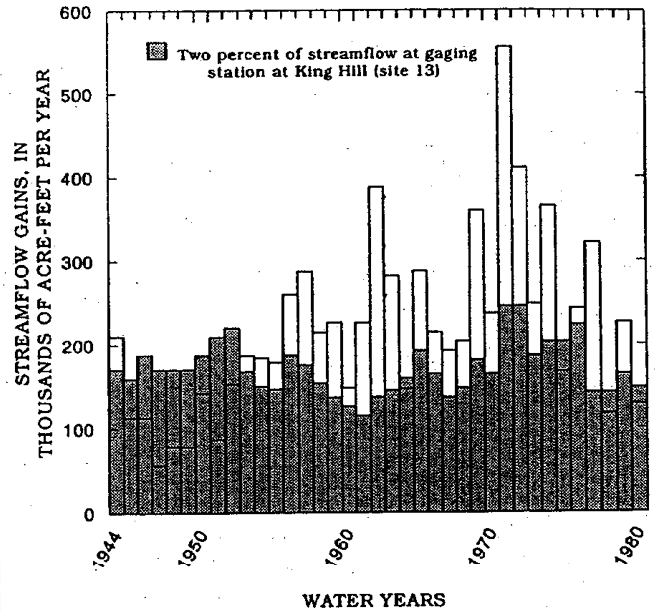


FIGURE 35.—Annual streamflow gains in the Snake River between King Hill (site 13) and Murphy (site 14), water years 1944–80.

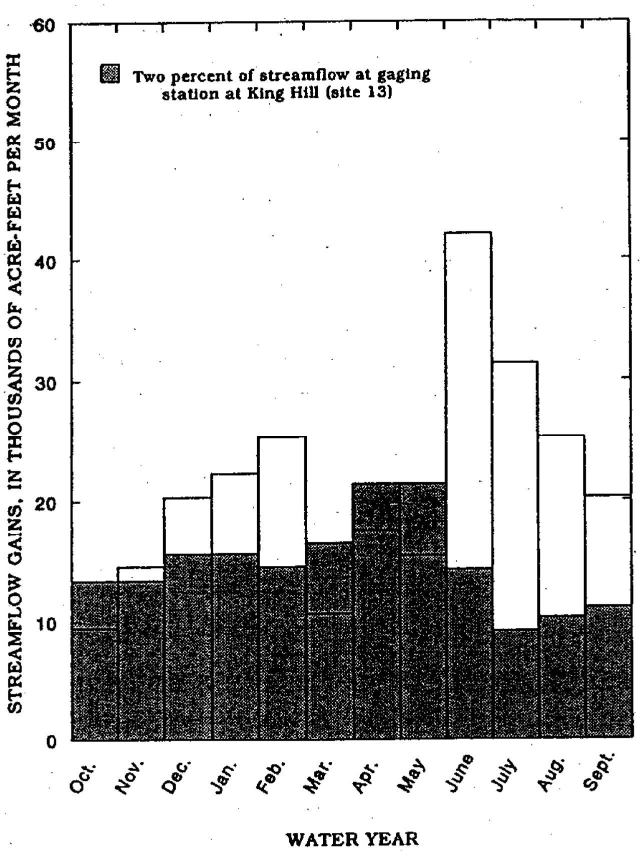


FIGURE 34.—Average monthly streamflow gains in the Snake River between King Hill (site 13) and Murphy (site 14), water years 1975–80.

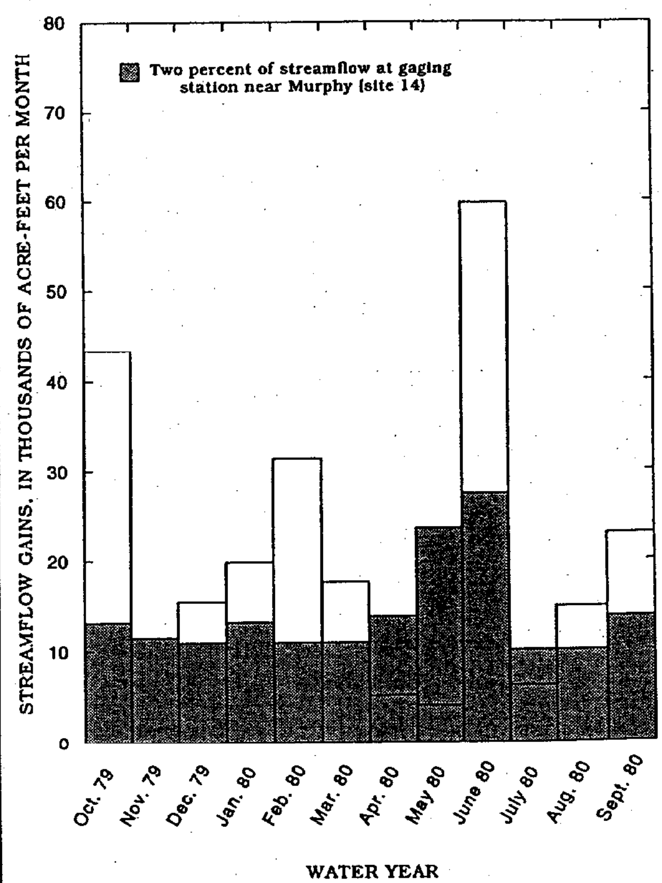


FIGURE 36.—Monthly streamflow gains in the Snake River between Murphy (site 14) and Nyssa (site 15), water year 1980.

water table along the Snake River from Nyssa to Weiser and generally correlate with streamflow gains and losses.

GROUND-WATER BUDGETS

Ground-water budgets were estimated for the eastern and western parts of the Snake River Plain. In the eastern plain, most ground water discharges to the Snake River as springs and, in the western plain, to the Snake and Boise Rivers as seepage.

The ground-water-flow system north of the Snake River is largely independent of the system south of the river because the Snake River functions as a line sink. Therefore, the eastern plain was analyzed in two parts. The main part of the eastern plain (fig. 39) includes the area on both sides of the Snake River upstream from Neeley and the area north of the Snake River between Neeley and King Hill. The main part of the eastern plain generally coincides with the Snake River Plain aquifer as defined by Mundorff and others (1964, p. 142). The southern part of the eastern plain is the area south of the Snake River between Neeley and Salmon Falls Creek. The boundary between the southern part of the eastern plain and the western plain is along Salmon Falls Creek (pl. 1).

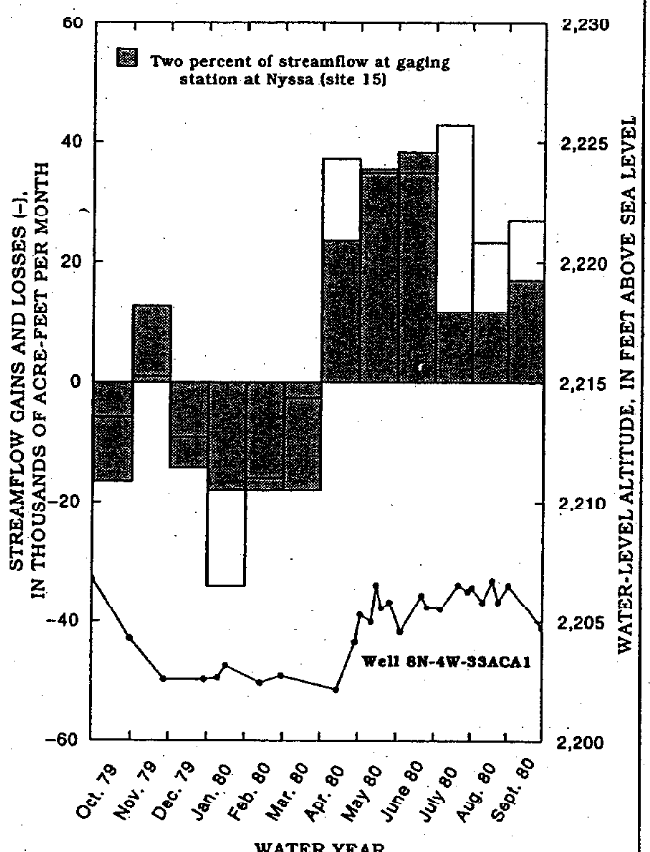


FIGURE 37.—Monthly streamflow gains and losses in the Snake River between Nyssa (site 15) and Weiser (site 16) and water levels from periodic measurements in well 8N-4W-33ACA1, water year 1980.

MAIN PART OF THE EASTERN SNAKE RIVER PLAIN

Annual ground-water budgets for the main part of the eastern Snake River Plain were estimated for water years 1912–80 (table 12). Sources of recharge, in order of decreasing magnitude, were (1) infiltration of irrigation water diverted from the Snake River and tributaries, plus seepage from tributaries flowing onto the plain and ground-water discharge from tributary drainage basins; (2) infiltration of precipitation on the plain; and (3) streamflow losses from the Snake River.

Total recharge to the main part of the eastern Snake River Plain consists of the above three components. Annual recharge and the components from which recharge was calculated for water years 1912–80 are listed in table 12. To estimate values for component 1, three items were considered: (*A*) water diverted from

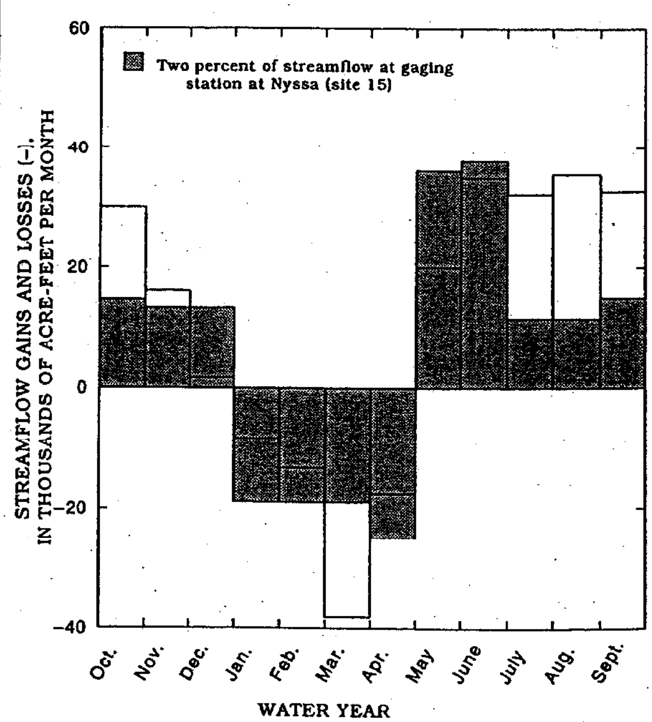


FIGURE 38.—Average monthly streamflow gains and losses in the Snake River between Nyssa (site 15) and Weiser (site 16), water years 1975–79.

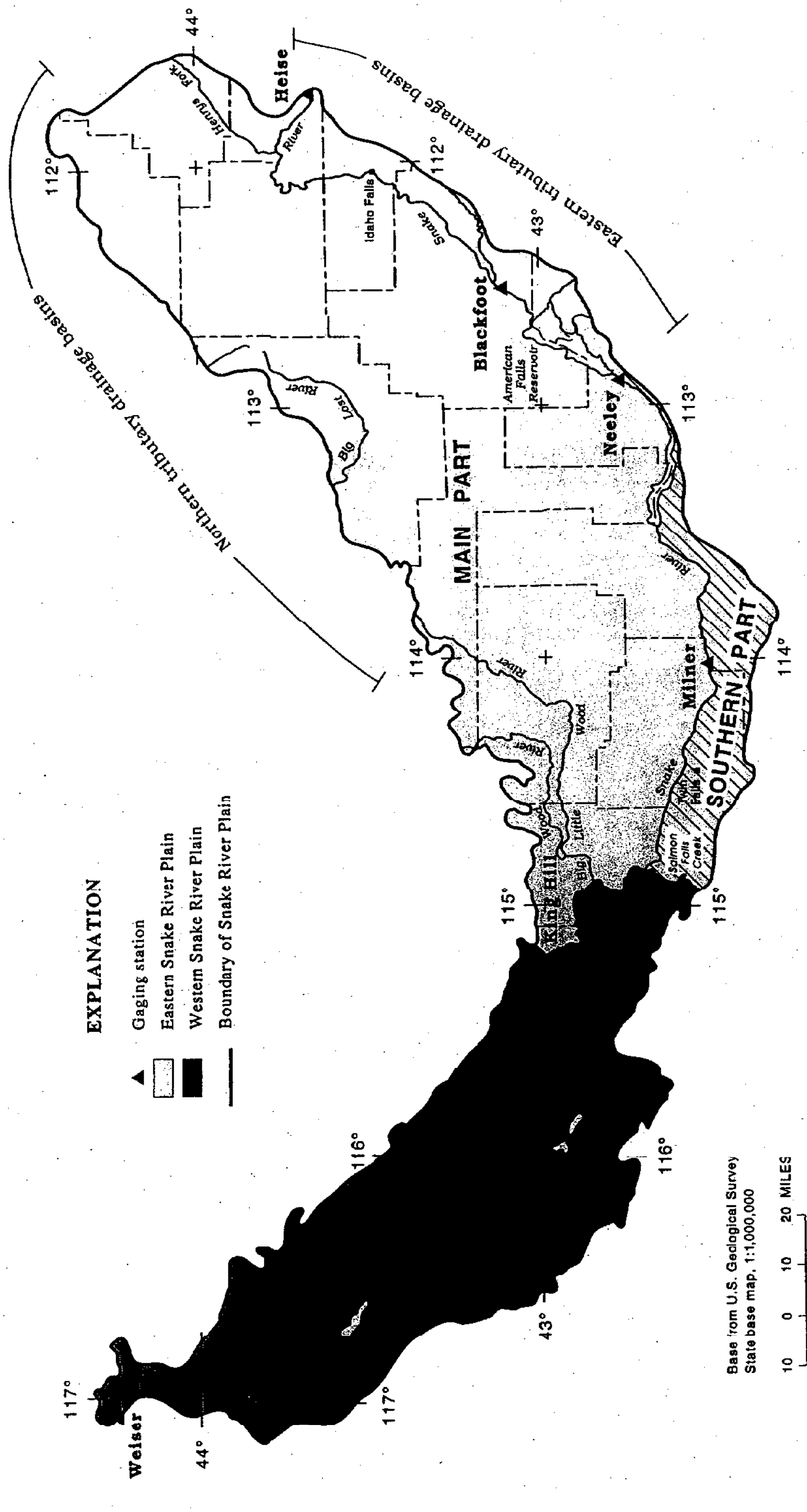


FIGURE 39.—Ground-water-budget areas.

TABLE 12.—*Ground-water budgets for the main part of the eastern Snake River Plain, water years 1912–80*

[Values in thousands of acre-feet]

	A Surface-water diversions: minus irrigation-return flow to the Snake River		B Tributary drainage basins: streamflow, diversions, ground-water discharge					C	1	2	3			Change in ground-water storage	
Water year	Heise to Neeley	Neeley to King Hill	Henrys Fork	Little and Big Wood Rivers	North side	East side	South side	Consumptive use of diverted or pumped water	Recharge from irrigation and tributary drainage basins (A+B-C)	Recharge from precipitation on the main part of the eastern plain	Recharge from streamflow losses in the Snake River	Total recharge (1+2+3)	Discharge	Annual	Cumulative
1912	1,760	1,470	680	490	1,240	120	20	950	4,830	1,010	500	6,340	5,300	1,040	1,040
1913	1,830	1,490	700	490	1,640	100	30	1,010	5,270	660	510	6,440	5,280	1,160	2,200
1914	1,970	1,420	720	600	1,560	130	30	1,070	5,360	560	520	6,440	5,260	1,180	3,380
1915	1,660	1,140	750	370	900	80	30	1,130	3,800	360	820	4,980	5,120	-140	3,240
1916	2,110	1,440	760	600	1,610	90	30	1,200	5,440	760	640	6,840	5,200	1,840	5,080
1917	2,250	1,390	760	630	2,040	100	30	1,260	5,940	560	280	6,780	5,440	1,340	6,420
1918	2,550	1,460	800	460	1,140	100	30	1,340	5,200	470	610	6,280	5,610	670	7,090
1919	2,020	1,000	800	380	960	90	40	1,240	4,050	470	910	5,430	5,660	-230	6,860
1920	2,560	1,440	800	230	950	90	40	1,360	4,750	390	530	5,670	5,530	140	7,000
1921	2,540	1,420	820	580	1,530	140	40	1,390	5,680	850	750	7,280	5,760	1,520	8,520
1922	2,570	1,340	820	590	1,590	120	40	1,390	5,680	530	560	6,770	5,780	990	9,510
1923	2,690	1,440	820	530	1,330	100	50	1,400	5,560	310	470	6,340	5,950	390	9,900
1924	2,470	910	750	240	900	80	50	1,340	4,060	470	390	4,920	5,830	-910	8,990
1925	2,760	1,560	820	550	1,320	90	50	1,390	5,760	840	400	7,000	5,590	1,410	10,400
1926	2,620	1,270	800	320	800	80	50	1,340	4,600	450	300	5,350	5,890	-540	9,860
1927	2,840	1,620	850	560	1,180	90	50	1,400	5,790	620	420	6,830	5,810	1,020	10,880
1928	2,960	1,660	850	450	1,130	90	60	1,400	5,800	550	340	6,690	6,240	450	11,330
1929	2,950	1,530	850	230	790	80	60	1,400	5,090	580	300	5,970	6,100	-130	11,200
1930	2,880	1,580	850	290	960	60	60	1,390	5,290	310	400	6,000	6,120	-120	11,080
1931	2,360	1,620	750	180	690	60	60	1,340	4,380	410	490	5,280	6,130	-850	10,230
1932	2,840	1,880	850	180	1,090	70	60	1,400	5,570	540	680	6,790	6,040	750	10,980
1933	2,860	1,920	850	340	880	70	60	1,410	5,570	420	720	6,710	6,150	560	11,540
1934	3,080	1,250	850	260	540	40	60	1,320	4,760	400	680	5,840	6,110	-270	11,270
1935	2,600	1,570	980	320	970	50	60	1,410	5,140	490	760	6,390	5,900	490	11,760
1936	2,900	1,810	920	320	820	70	60	1,430	5,470	680	580	6,730	6,190	540	12,300
1937	2,740	1,810	890	290	700	70	60	1,450	5,110	400	510	6,020	6,240	-220	12,080
1938	3,080	1,880	840	550	1,510	80	60	1,450	6,550	1,000	460	8,010	6,310	1,700	13,780
1939	3,030	1,980	900	380	1,030	70	60	1,460	5,990	530	410	6,930	6,360	570	14,350
1940	2,760	1,870	910	320	960	60	60	1,470	5,470	570	410	6,450	6,360	90	14,440
1941	2,800	1,830	810	370	1,000	70	60	1,470	5,470	460	340	6,270	6,400	-130	14,310
1942	2,900	1,970	930	460	1,410	80	60	1,490	6,320	480	370	7,170	6,530	640	14,950
1943	3,150	1,960	910	590	1,770	100	60	1,520	7,020	900	370	8,290	6,800	1,490	16,440
1944	2,720	1,870	840	390	1,650	80	70	1,540	6,080	330	450	6,860	6,570	290	16,730
1945	2,860	1,940	770	340	1,260	100	70	1,540	5,800	420	550	6,770	6,750	20	16,750
1946	3,170	1,980	860	440	1,260	110	70	1,560	6,330	560	410	7,300	6,750	550	17,300
1947	3,180	1,980	930	410	1,320	80	70	1,610	6,360	490	320	7,170	6,770	400	17,700
1948	2,950	1,990	790	350	1,300	90	70	1,670	5,870	430	260	6,560	6,820	-260	17,440
1949	3,210	1,980	920	380	1,110	80	70	1,720	6,030	540	290	6,860	6,710	150	17,590
1950	3,150	2,030	760	430	1,040	130	80	1,790	5,830	590	120	6,540	6,660	-120	17,470
1951	3,200	2,080	770	470	1,380	90	80	1,860	6,210	530	180	6,920	6,900	20	17,490
1952	3,320	2,100	840	660	1,780	110	80	1,930	6,960	510	250	7,720	6,940	780	18,270
1953	3,150	2,060	940	430	1,390	90	80	2,010	6,130	410	200	6,740	6,810	-70	18,200
1954	3,320	2,120	960	400	1,180	70	80	2,070	6,060	360	120	6,540	6,840	-300	17,900
1955	2,990	2,040	850	310	1,000	60	80	2,130	5,200	330	160	5,690	6,860	-1,170	16,730
1956	3,440	2,080	900	550	1,620	70	80	2,190	6,550	540	150	7,240	6,700	540	17,270
1957	3,200	2,070	880	470	1,410	90	80	2,280	5,920	560	210	6,690	6,710	-20	17,250
1958	3,260	2,140	890	540	1,750	90	80	2,330	6,420	460	50	6,930	6,730	200	17,450
1959	3,400	2,090	990	310	970	70	80	2,380	5,530	240	210	5,980	6,490	-510	16,940
1960	3,280	2,080	1,000	320	880	60	80	2,430	5,270	330	300	5,900	6,660	-760	16,180
1961	2,790	1,590	970	200	740	50	80	2,480	3,940	400	410	4,750	6,400	-1,650	14,530
1962	3,290	1,960	900	380	1,050	90	80	2,500	5,250	580	160	5,990	6,280	-290	14,240
1963	2,880	2,000	920	370	1,310	80	80	2,510	5,130	380	330	5,840	6,470	-630	13,610
1964	3,000	2,000	940	360	1,410	90	80	2,600	5,280	410	240	5,930	6,390	-460	13,150
1965	3,150	2,050	910	640	2,330	110	80	2,620	6,650	760	320	7,730	6,450	1,280	14,430
1966	3,280	2,230	1,020	480	1,110	70	80	2,640	5,630	430	400	6,460	6,440	20	14,450
1967	3,150	2,150	960	490	2,030	80	80	2,660	6,280	390	240	6,910	6,200	710	15,160
1968	3,120	2,120	870	320	1,180	80	80	2,680	5,090	450	160	5,700	6,540	-840	14,320
1969	3,450	2,180	940	660	2,270	110	80	2,690	7,000	640	200	7,840	6,600	1,240	15,560
1970	3,170	2,070	860	340	1,520	90	80	2,710	5,420	690	180	6,290	6,590	-300	15,260
1971	3,250	2,110	960	580	1,830	150	80	2,730	6,230	830	100	7,160	6,720	440	15,700
1972	3,480	2,160	810	440	1,560	170	80	2,740	5,960	1,020	140	7,120	6,440	680	16,380
1973	3,500	2,070	860	330	1,200	120	70	2,750	5,400	600	160	6,160	6,310	-150	16,230
1974	3,660	2,070	910	590	1,880	140	70	2,770	6,550	860	130	7,540	6,450	1,090	17,320
1975	3,330	1,900	790	510	1,860	150	70	2,780	5,830	840	70	6,740	6,510	230	17,550
1976	3,300	1,990	560	390	1,550	140	70	2,790	5,210	680	160	6,050	6,850	-800	16,750
1977	2,890	1,660	830	180	940	60	70	2,810	3,820	160	200	4,180	6,680	-2,500	14,250
1978	2,990	1,640	890	460	1,320	100	60	2,830	4,630	740	120	5,490	6,210	-720	13,530
1979	3,420	1,920	970	360	1,180	80	60	2,850	5,140	410	360	5,910	6,440	-530	13,000
1980	3,140	1,880	820	390	1,470	80	60	2,870	4,970	600	340	5,910	6,320	-410	12,590

the Snake River for irrigation (minus irrigation-return flow); (*B*) water diverted from tributaries for irrigation (minus irrigation-return flow to the Snake River), seepage from tributaries flowing onto the plain, and ground-water discharge from tributary basins; and (*C*) consumptive use (evapotranspiration losses) of water diverted or pumped for irrigation. Component 1 is considered to be $A+B-C$. Water pumped for irrigation was assumed to be the sum of water consumptively used and the water returned to the aquifer.

Consumptive use of irrigation water was estimated from irrigated acreage times estimated evapotranspiration (*ET*) rates. Estimates of irrigated acreage prior to 1946 (Simons, 1953) were compared with estimates of acreage from maps of irrigated acreage for 1929 (Hoyt, 1935) and 1945 (U.S. Bureau of Reclamation, 1946). Irrigated acreages after 1946 were estimated from maps of irrigated acreage for 1966 (Idaho Water Resource Board, 1970); 1975 (Idaho Department of Water Resources, 1978); and 1979 (unpublished maps compiled by the U.S. Bureau of Reclamation for the Pacific Northwest River Basins Commission). *ET* rates were estimated according to crop type, type of irrigation system, and geographic area. Rates given by Simons (1953), Norvitch and others (1969), and Sutter and Corey (1970) were used as guides for selecting the rates used in this study. Average *ET* rates used were 1.6 acre-ft/acre of crops irrigated by surface water and 1.4 acre-ft/acre of crops irrigated by ground water. Because the number of irrigated acres is not actually known for most years and *ET* rates may be estimated inaccurately, consumptive-use estimates probably offer significant errors in the estimates of recharge component 1; however, these may be less significant in the estimates of total recharge. For instance, a 20-percent error in consumptive use may produce only about a 5-percent error in the total recharge.

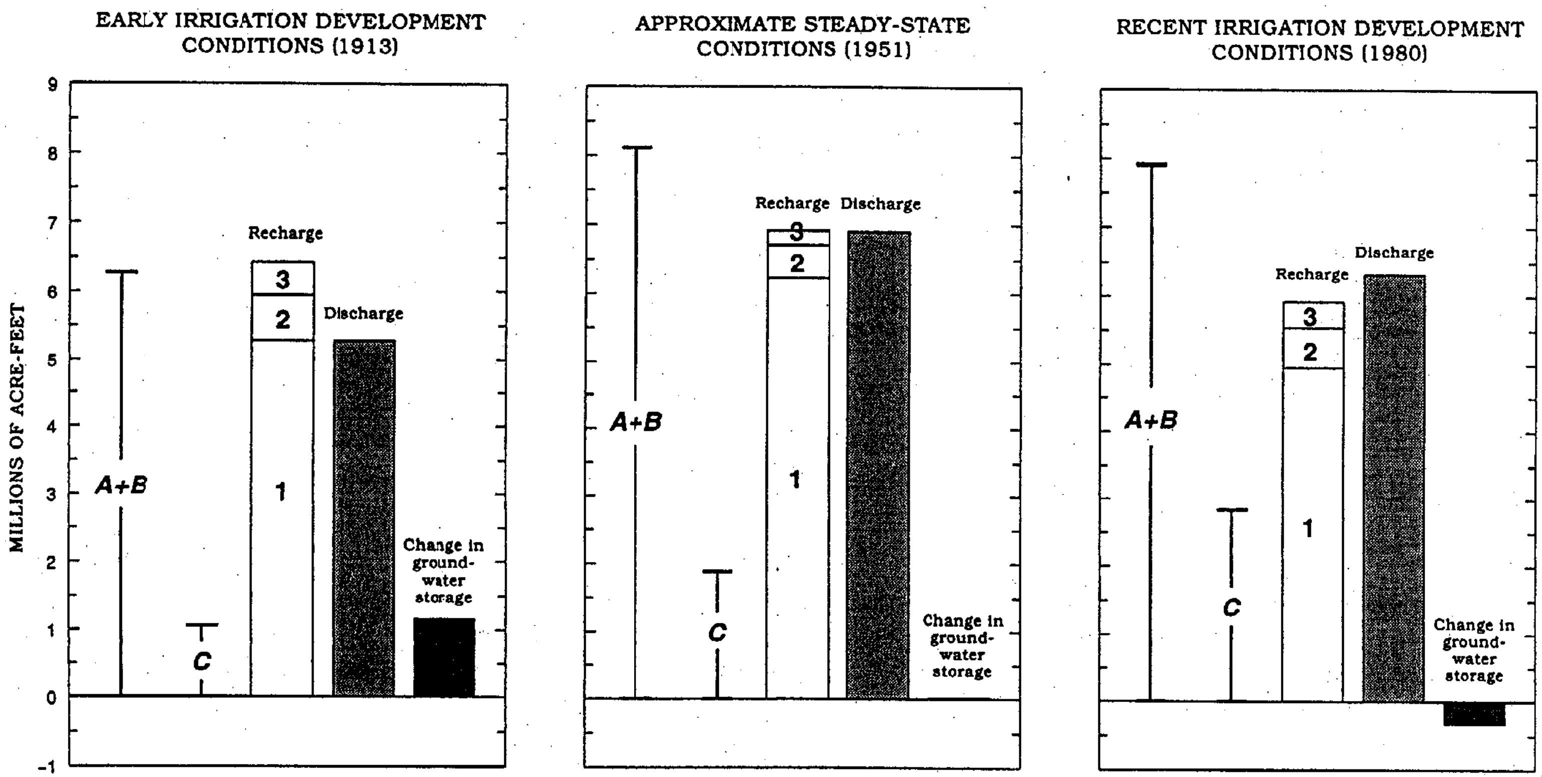
Recharge component 2 (table 12) consists of infiltration from precipitation on the main part of the eastern plain. Adjustments in the amount of annual recharge from precipitation were made on the basis of precipitation from October to March. From 1912 to 1980, average annual recharge from precipitation on the main part of the eastern plain was 540,000 acre-ft, which was about 90 percent of the recharge from precipitation on the entire eastern plain (600,000 acre-ft).

Recharge component 3 consists of streamflow losses from the Snake River to aquifers; these losses were quantified in the section "Streamflow Gains and Losses." Total recharge shown in table 12 is the sum of components 1, 2, and 3.

The relations between annual recharge (and its components), discharge, and change in ground-water storage during early irrigation development conditions (1913), approximate steady-state conditions (1951), and recent irrigation development conditions (1980) are shown in figure 40. Values for items *A* and *B* increased from 1913 to 1951 owing to an increase in surface-water diversions for irrigation. Consumptive use of water diverted or pumped for irrigation (item *C*) and net recharge from irrigation and tributary drainage basins (component 1) increased correspondingly from 1913 to 1951. Values for items *A* and *B* decreased slightly from 1951 to 1980 as a result of a decrease in surface-water diversions for irrigation. Consumptive use of irrigation water (item *C*) continued to increase, however, largely as a result of increases in development of ground water for irrigation.

Annual ground-water discharge to the north side of the Snake River between Milner and King Hill increased from a preirrigation (pre-1880) average of about 3.0 million acre-ft to almost 4.9 million acre-ft in 1951, an increase of about 1.9 million acre-ft. Ground-water discharge to the Snake River increased until it was about equal to the maximum recharge from water diverted for irrigation from the Snake River between Neeley and King Hill and from the Big and Little Wood Rivers (fig. 41). Recharge values were adjusted for ground-water pumpage for irrigation in the area. Ground-water discharge to the north side of the Snake River appears to increase or decrease in response to climatological variations; however, most of the change can be attributed to surface-water irrigation in the area downstream from Neeley.

Change in ground-water storage is the difference between the amount of ground-water recharge and the amount of discharge. In 1980, ground-water storage in the main part of the eastern plain decreased by about 410,000 acre-ft (table 12). From about 1880 (when surface-water irrigation began) to 1911, storage increased about 6 million acre-ft, based on estimates of annual recharge that were directly related to the number of irrigated acres. Cumulative annual changes in ground-water storage from 1912 to 1980 are shown in figure 42. The total cumulative increase in storage from 1880 to 1952 was about 24 million acre-ft. In the 12 years following 1952, storage decreased as ground-water pumpage increased substantially. From 1952 to 1980, storage decreased nearly 6 million acre-ft. Storage decreases from 1952 to 1964 also may be attributed to below-normal precipitation in 1955 and from 1959 to 1961, which resulted in less surface water available for irrigation and less recharge from precipitation. Precipitation was above normal for 8 of the 11 years from 1965 to 1975; therefore, more surface water was available for irrigation, and ground-water storage increased despite further increases in ground-water pumpage. Precipitation in northern tributary drainage basins also



EXPLANATION

1 Recharge from irrigation and tributary drainage basins (*A+B-C*)

A Snake River diversions (minus irrigation-return flow to the Snake River)

B Tributary drainage basins: streamflow, diversions (minus return flow), and ground-water discharge

C Consumptive use of diverted or pumped water

2 Recharge from precipitation on the main part of the eastern plain

3 Recharge from streamflow losses in the Snake River

FIGURE 40.—Annual ground-water budgets for the main part of the eastern Snake River Plain.

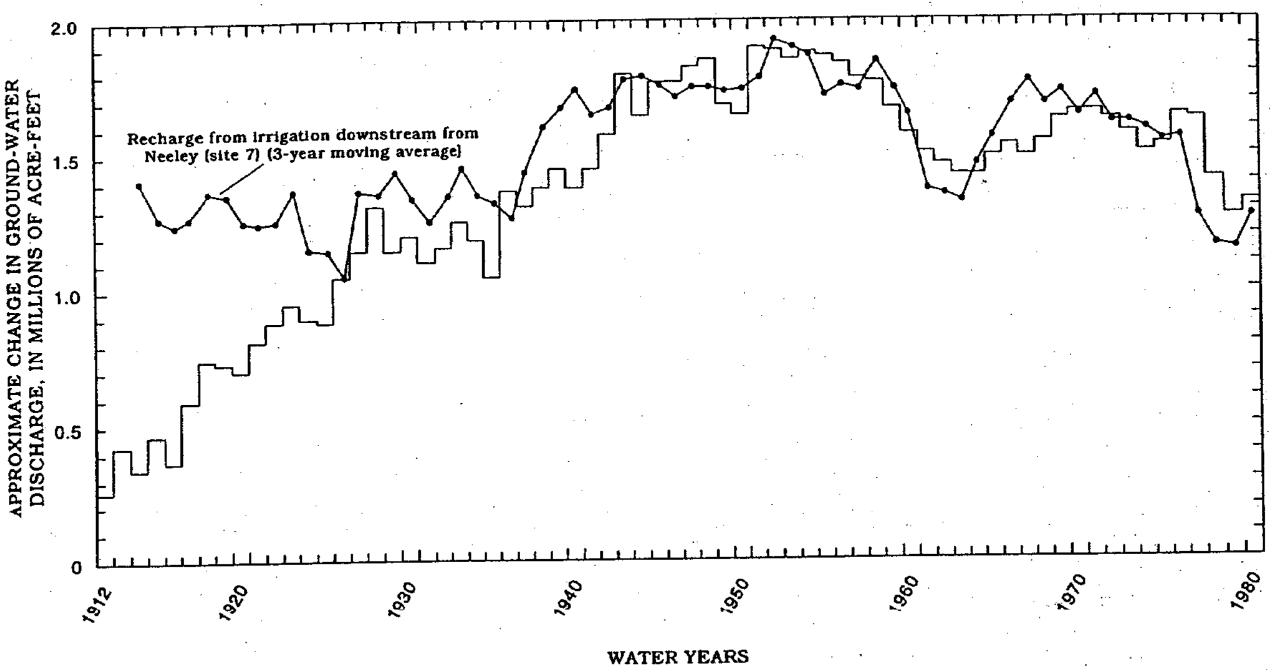


Figure 41.—Approximate change in ground-water discharge to the north side of the Snake River, from estimates in 1911, between Milner (site 9) and King Hill (site 13), water years 1912–80.

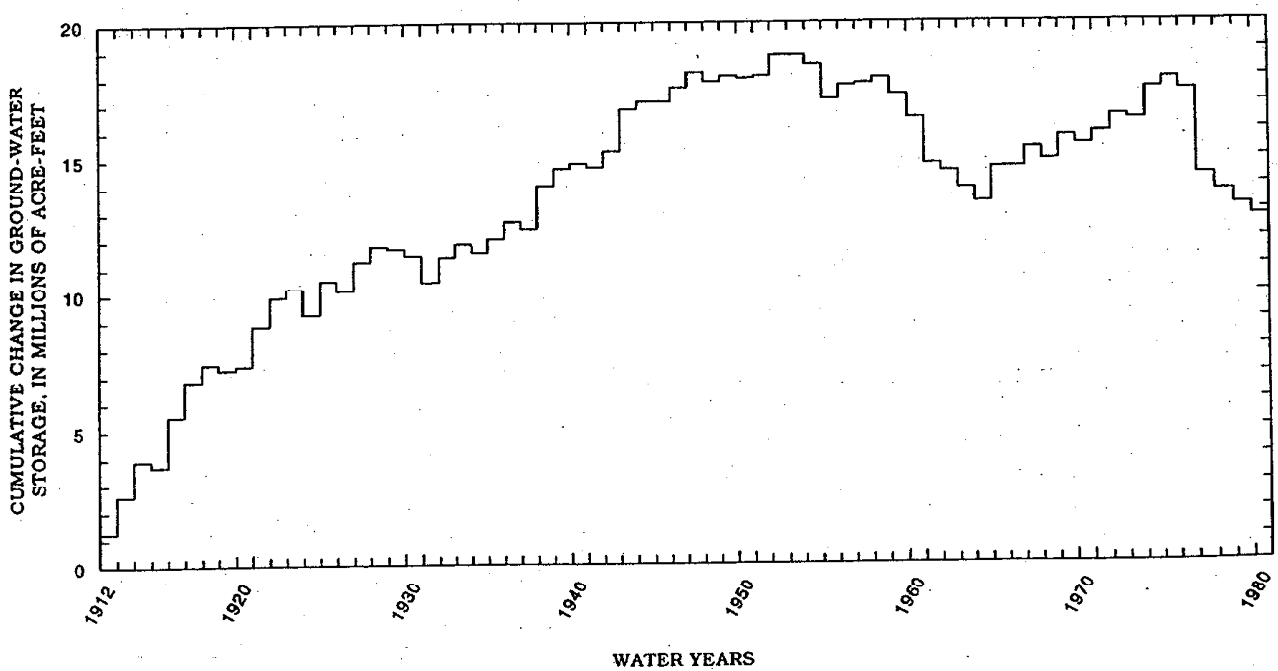


Figure 42.—Cumulative annual changes in ground-water storage, main part of the eastern Snake River Plain, water years 1912–80.

was above normal during that period. The period 1965–75 included the 6 years of greatest streamflow for 61 years of record at Big Lost River below Mackay Reservoir near Mackay and 40 years of record at Little Lost River near Howe (fig. 43).

After 1975, ground-water storage again decreased. Drought conditions prevailed during most of the water year 1977; precipitation was near the long-term average during the following years. Ground-water pumpage continued to increase and surface-water diversions decreased from 1974 to 1980. Increased irrigation efficiency, resulting from the use of sprinkler systems, decreased the amount of water available for recharge from surface-water irrigation.

The shape of the cumulative ground-water storage hydrograph in figure 42 is similar to that of the hydrograph of ground-water discharge to the north side of the Snake River between Milner and King Hill, shown in figure 27. Trends on the cumulative ground-water storage hydrograph also correspond with trends in regional ground-water levels (fig. 44). The water level in well 1N-29E-30BBD1 (pl. 1, site W10) in the central part of the eastern plain declined about 5 ft from 1952 to 1980. The water level in well 9S-19E-25BBC1 (pl. 1, site W16), at the downstream end of the eastern plain, declined about 12 ft from 1957 to 1980.

Mundorff and others (1964, p. 210) stated that an average water-level rise of 10 ft in the basaltic aquifer underlying the eastern plain represents an increase of about 5 million acre-ft of water in ground-water storage. From 1957 to 1980, ground-water levels in

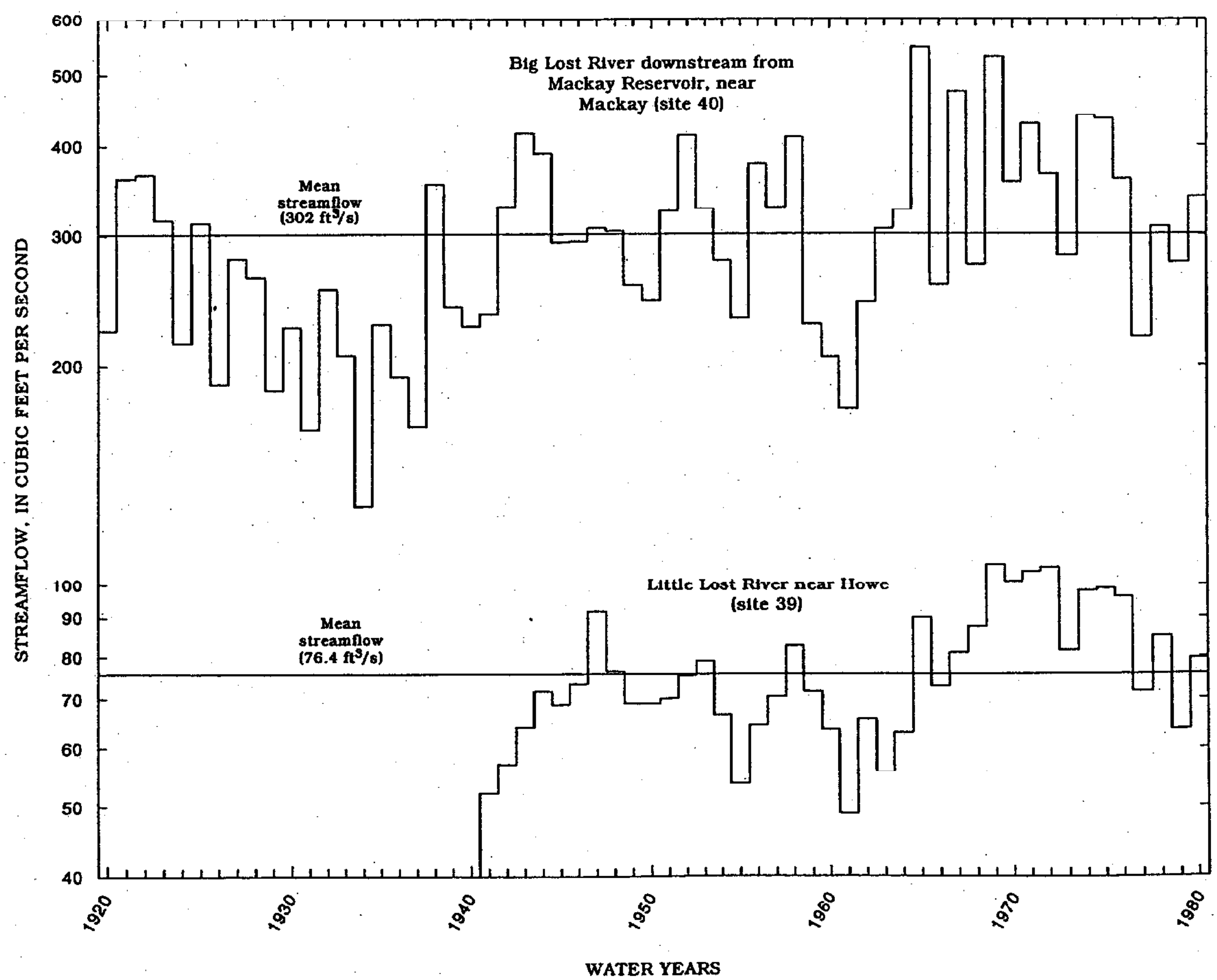


FIGURE 43.—Annual streamflow in Big Lost and Little Lost Rivers, water years 1920–80.

the eastern plain declined 5 to 12 ft in the wells shown in figure 44. Correspondingly, the cumulative storage hydrograph indicates a decrease of about 5 million acre-ft of water during the same period.

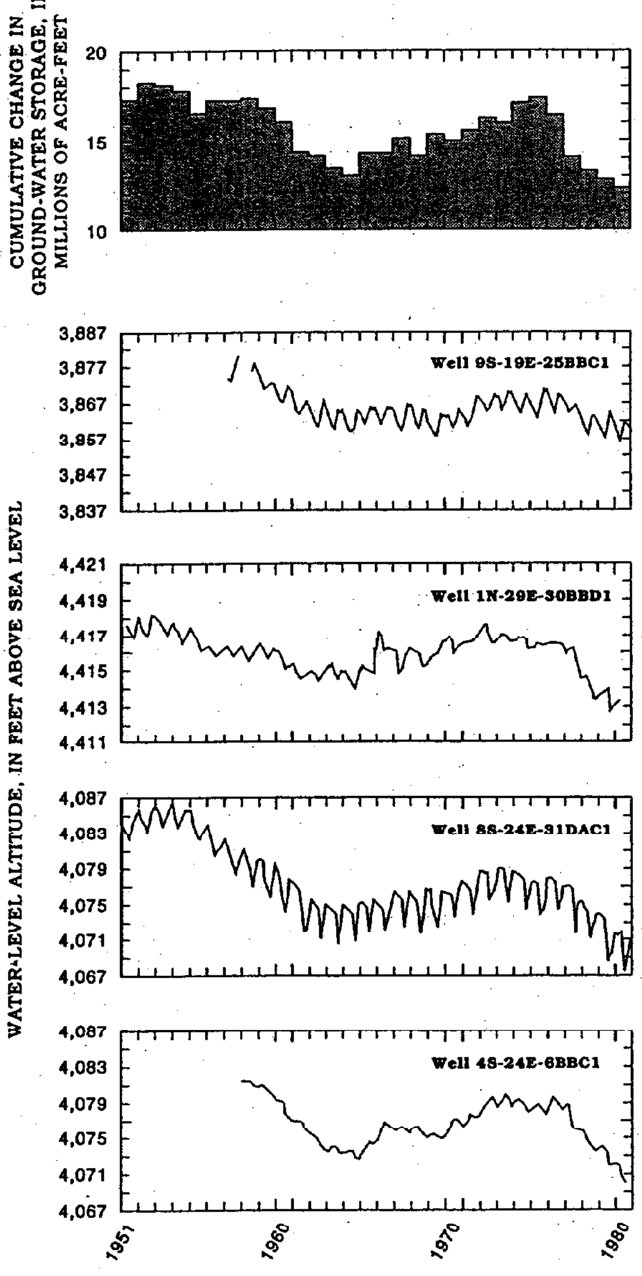


FIGURE 44.—Cumulative annual changes in ground-water storage and water levels in selected wells, main part of the eastern Snake River Plain, water years 1951–80.

Mundorff and others (1964, p. 162) listed depth to water in 15 wells, each measured once between 1890 and 1912 and again during the 1950's. They conceded possible measurement errors for three wells. If these measurements were omitted from calculations, the average water-level rise during the interim period was 55 ft. If Mundorff and others' ratio of 5 million acre-ft of storage to 10 ft of water-level change were applied to the 24 million acre-ft increase in storage from 1880 to 1952, the average water-level rise would be nearly 50 ft, as observed. Therefore, estimated increases and decreases in ground-water storage seem to correspond with long-term water-level changes.

SOUTHERN PART OF THE EASTERN SNAKE RIVER PLAIN

Annual ground-water budgets for the area south of the Snake River between Neeley and Salmon Falls Creek were estimated for water years 1912–80 (table 13). Sources of recharge, in order of decreasing magnitude, were (1) infiltration of irrigation water diverted from the Snake River and tributaries, plus seepage from tributaries flowing onto the plain and ground-water discharge from tributary drainage basins; and (2) infiltration of precipitation on the plain. Total recharge to the southern part of the eastern plain consists of the above two components. Annual recharge and the components from which recharge was calculated for water years 1912–80 are listed in table 13. To estimate values for component 1, four items were considered: (*A*) water diverted from the Snake River for irrigation (minus irrigation-return flow), (*B*) water (streamflow and ground-water discharge) from tributary drainage basins, (*C*) surface-water discharge to the Snake River, and (*D*) consumptive use of water diverted or pumped for irrigation. Component 1 is considered to be $A+B-C-D$.

Recharge component 2 (table 13) consists of infiltration from precipitation on the southern part of the eastern plain. Adjustments in the amount of annual recharge from precipitation were made on the basis of precipitation from October to March. From 1912 to 1980, average annual recharge from precipitation on the southern part of the eastern plain was 60,000 acre-ft. Total recharge shown in table 13 is the sum of components 1 and 2.

Ground-water discharge to the Snake River and its tributaries in the southern part of the eastern plain increased shortly after irrigation with surface water began. Raised ground-water levels caused small springs and seeps to develop along the reach between Milner and Hagerman. The largest amount of ground-water discharge to the Snake River from the southern part of the plain is between Milner and

TABLE 13.—*Ground-water budgets for the southern part of the eastern Snake River Plain, water years 1912–80*

[Values in thousands of acre-feet]

Water year	*A* Snake River diversions	*B* Tributary drainage basins: streamflow, diversions, ground-water discharge	*C* Surface-water discharge to the Snake River	*D* Consumptive use of diverted or pumped water	*1* Recharge from irrigation and tributary drainage basins (*A*+*B*-*C*-*D*)	*2* Recharge from precipitation on the southern part of the eastern plain	Total recharge (1 + 2)	Discharge	Change in ground-water storage: Annual	Change in ground-water storage: Cumulative
1912	1,140	630	460	430	880	110	990	340	650	650
1913	1,240	450	620	500	570	70	640	370	270	920
1914	1,320	560	850	580	450	60	510	380	130	1,050
1915	1,300	280	780	560	240	40	280	380	-100	950
1916	1,600	430	1,270	620	140	70	210	380	-170	780
1917	1,800	520	1,180	670	470	60	530	380	150	930
1918	1,730	390	720	660	740	50	790	380	410	1,340
1919	1,330	400	620	650	460	50	510	400	110	1,450
1920	1,600	450	810	660	580	40	620	410	210	1,660
1921	1,460	1,000	820	680	960	90	1,050	420	630	2,290
1922	1,530	590	810	680	630	60	690	440	250	2,540
1923	1,590	490	800	690	590	30	620	450	170	2,710
1924	1,370	380	530	650	570	50	620	460	160	2,870
1925	1,560	450	660	690	660	90	750	470	280	3,150
1926	1,590	280	660	650	560	50	610	480	130	3,280
1927	1,670	400	800	690	580	70	650	490	160	3,440
1928	1,730	380	940	690	480	60	540	500	40	3,480
1929	1,640	370	850	690	470	70	540	500	40	3,520
1930	1,650	240	680	670	540	30	570	500	70	3,590
1931	1,620	200	660	640	520	50	570	500	70	3,660
1932	1,600	410	690	680	640	60	700	500	200	3,860
1933	1,800	300	850	680	570	50	620	510	110	3,970
1934	1,470	170	610	630	400	50	450	510	-60	3,910
1935	1,600	260	570	680	610	50	660	510	150	4,060
1936	1,680	350	770	700	560	70	630	520	110	4,170
1937	1,650	280	740	700	490	40	530	520	10	4,180
1938	1,640	370	780	710	520	110	630	520	110	4,290
1939	1,760	350	890	710	510	60	570	520	50	4,340
1940	1,640	230	710	710	450	60	510	540	-30	4,310
1941	1,600	250	700	710	440	50	490	530	-40	4,270
1942	1,580	560	870	720	550	50	600	520	80	4,350
1943	1,690	570	910	730	620	100	720	540	180	4,530
1944	1,520	440	590	730	640	40	680	540	140	4,670
1945	1,590	470	710	730	620	50	670	550	120	4,790
1946	1,660	480	700	740	700	60	760	550	210	5,000
1947	1,660	310	640	760	570	50	620	560	60	5,060
1948	1,690	330	630	760	630	50	680	560	120	5,180
1949	1,660	460	710	780	630	60	690	560	130	5,310
1950	1,670	420	760	790	540	70	610	570	40	5,350
1951	1.700	550	730	800	720	60	780	580	200	5,550
1952	1,760	560	680	810	830	60	890	590	300	5,850
1953	1,750	420	710	820	640	50	690	600	90	5,940
1954	1,780	240	580	830	610	40	650	600	50	5,990
1955	1,650	240	600	840	450	40	490	600	-110	5,880
1956	1,720	420	640	850	650	60	710	600	110	5,990
1957	1,660	450	630	870	610	60	670	600	70	6,060
1958	1,680	480	650	890	620	50	670	600	70	6,130
1959	1,680	260	510	900	530	30	560	600	-40	6,090
1960	1,720	280	520	910	570	40	610	600	10	6,100
1961	1,520	220	440	920	380	40	420	600	-180	5,920
1962	1,600	550	540	930	680	60	740	600	140	6,060
1963	1,560	320	520	940	420	40	460	600	-140	5,920
1964	1,630	440	540	940	590	40	630	600	30	5,950
1965	1,700	510	730	950	530	80	610	600	10	5,960
1966	1,800	290	650	950	490	50	540	600	-60	5,900
1967	1,700	310	600	950	460	40	500	600	-100	5,800
1968	1,690	240	630	950	350	50	400	600	-200	5,600
1969	1,760	420	690	960	530	70	600	590	10	5,610
1970	1,580	470	740	960	350	80	430	590	-160	5,450
1971	1,620	670	770	960	560	90	650	580	70	5,520
1972	1,650	650	1,150	960	190	110	300	590	-290	5,230
1973	1,560	540	980	960	160	70	230	570	-340	4,890
1974	1,620	570	920	950	320	100	420	550	-130	4,760
1975	1,460	680	820	950	370	90	460	550	-90	4,670
1976	1,580	580	810	960	390	70	460	550	-90	4,580
1977	1,480	330	470	960	380	20	400	540	-140	4,440
1978	1,420	450	550	970	350	80	430	540	-110	4,330
1979	1,520	470	460	980	550	40	590	530	60	4,390
1980	1,460	540	570	980	450	70	520	530	-10	4,380

Hagerman, where seepage is largely from surface-water-irrigated land. Ground-water discharge to the Snake River between Neeley and Minidoka is largely ground-water seepage from tributary drainage basins. Streamflow gains in the Snake River from ground-water discharge are discussed in the section "Streamflow Gains and Losses."

Ground-water flow beneath the Snake River from south to north was a component of recharge to the main part of the eastern plain and a component of discharge for the area south of the river. The column titled "Discharge" in table 13 includes flow beneath and to the Snake River.

Storage was estimated to have increased about 2 million acre-ft prior to 1912. This value was based on estimated irrigated acreage prior to 1912 and the assumption that rates of water application and return flow were proportional to those from 1912 to 1980. Ground-water storage continued to increase from 1912 to 1952 (fig. 45), with the exception of drought years. From 1952 to 1965, the amount of water in storage was relatively constant; from 1966 to 1980, storage decreased. Part of the decrease in storage was due to a decrease in infiltration from surface water used for irrigation—the result of a 10-percent decrease in Snake River diversions from 1975 to 1980. The decrease in diversions was due partly to an increase in irrigation efficiency resulting from the use of sprinkler systems.

Ground-water levels in the southern part of the eastern plain rose rapidly after irrigation with surface water began. In northern Twin Falls County, water levels in 1905 averaged about 250 ft below land surface (Stearns and others, 1938, p. 129). Within 8 years after surface-water irrigation began, water levels rose as much as 200 ft. From 1909 to 1912, water levels in 29 wells rose an average of 25 ft/yr. Stearns and others (1938, p. 129) stated that the average water-level rise from 1913 to 1928 was about 4 ft/yr, and that about 6 million acre-ft of water was added to aquifer storage from 1906 to 1928.

Little historical water-level information is available for northern Cassia County. In the area supplied with irrigation water from Lake Walcott, infiltrating water is perched above the regional water table by relatively impermeable sediments. Seepage from the perched aquifer supplies ground-water discharge to the Snake River between Minidoka and Burley.

Water levels measured in wells from the 1950's to 1980 indicate different trends of water-level rises and declines due to areal variations in ground-water recharge and discharge. Of 40 wells measured in Cassia and Twin Falls Counties from 1971 to 1982, water levels in 25 wells declined an average of 1.25 to 5.00 ft/yr (Young and Norvitch, 1984). However, water levels in seven wells rose from 0.15 to 4.00 ft/yr, and no trend was detected in eight other wells. Water levels declined in an area where ground water was used for irrigation (fig. 46; hydrographs *A*, *B*, *D*). Hydrograph *C* (fig. 46) shows that water levels in an area where surface water was used for irrigation remained relatively stable.

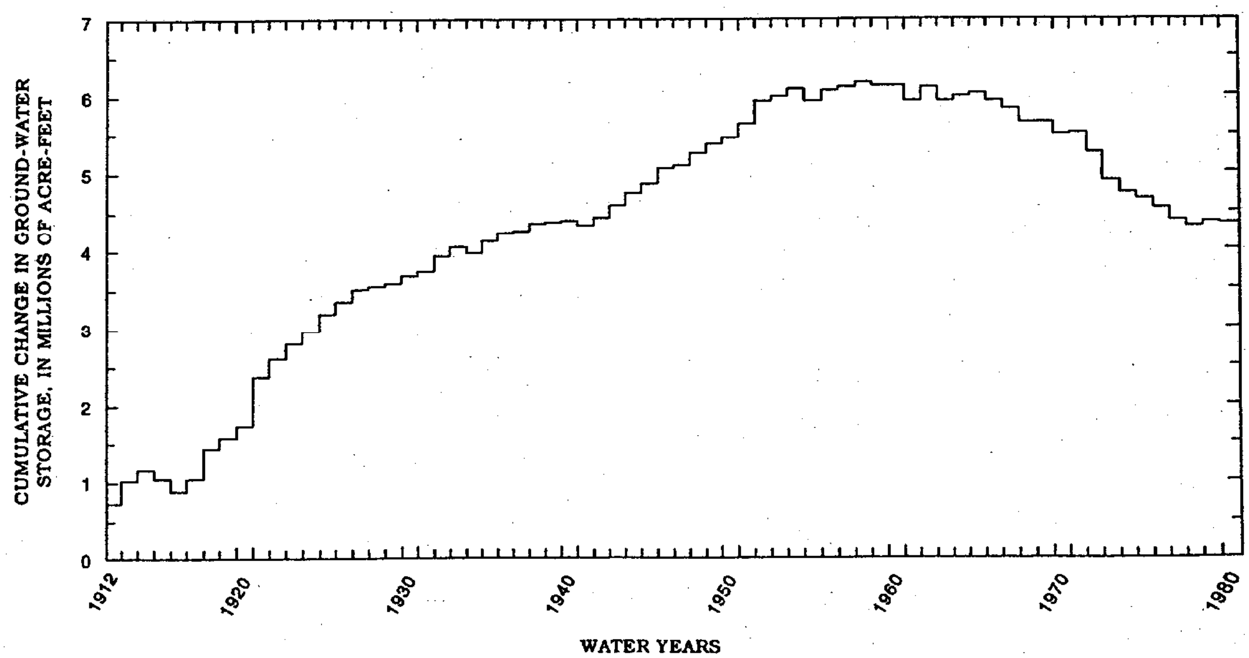


FIGURE 45.—Cumulative annual changes in ground-water storage, southern part of the eastern Snake River Plain, water years 1912–80.

WESTERN SNAKE RIVER PLAIN

Annual ground-water budgets for the western Snake River Plain were estimated for water years 1930–80 (table 14). Sources of recharge, in order of decreasing magnitude, were (1) infiltration of irrigation water diverted from the Snake River and tributaries, plus ground-water discharge from tributary drainage basins; and (2) infiltration of precipitation on the plain.

Total recharge to the western Snake River Plain consists of the above two components. Annual recharge and the components from which recharge was calculated for water years 1930–80 are listed in table 14. To estimate values for component 1, three items were considered: (*A*) water diverted from the Snake River and tributaries for irrigation (minus irrigation-return flow), (*B*) ground-water discharge from tributary drainage basins, and (*C*) consumptive use of water diverted or pumped for irrigation. Ground-water discharge from the tributary drainage basins was assumed to be stable throughout the estimation period. Component 1 is considered to be A+B–C.

Recharge component 2 consists of infiltration from precipitation on the western plain. Adjustments in the amount of annual recharge from precipitation were made on the basis of precipitation from October to March. From 1930 to 1980, average annual recharge from precipitation on the western plain was 100,000 acre-ft. Total recharge shown in table 14 is the sum of components 1 and 2.

Ground-water discharge in the western plain is seepage to the Snake, Boise, Payette, Owyhee, and Weiser Rivers and to irrigation drains. Drains are used in areas that have become waterlogged from the application of surface water for irrigation in excess of crop needs. Most drains in the western plain are in the Boise River valley. The following is a summary of the distribution of ground-water discharge in 1980:

River	*Ground-water discharge (thousands of acre-feet)*
Snake	500
Boise	360
Payette	160
Owyhee	40
Weiser	10
Irrigation drains	460
Total	1,530

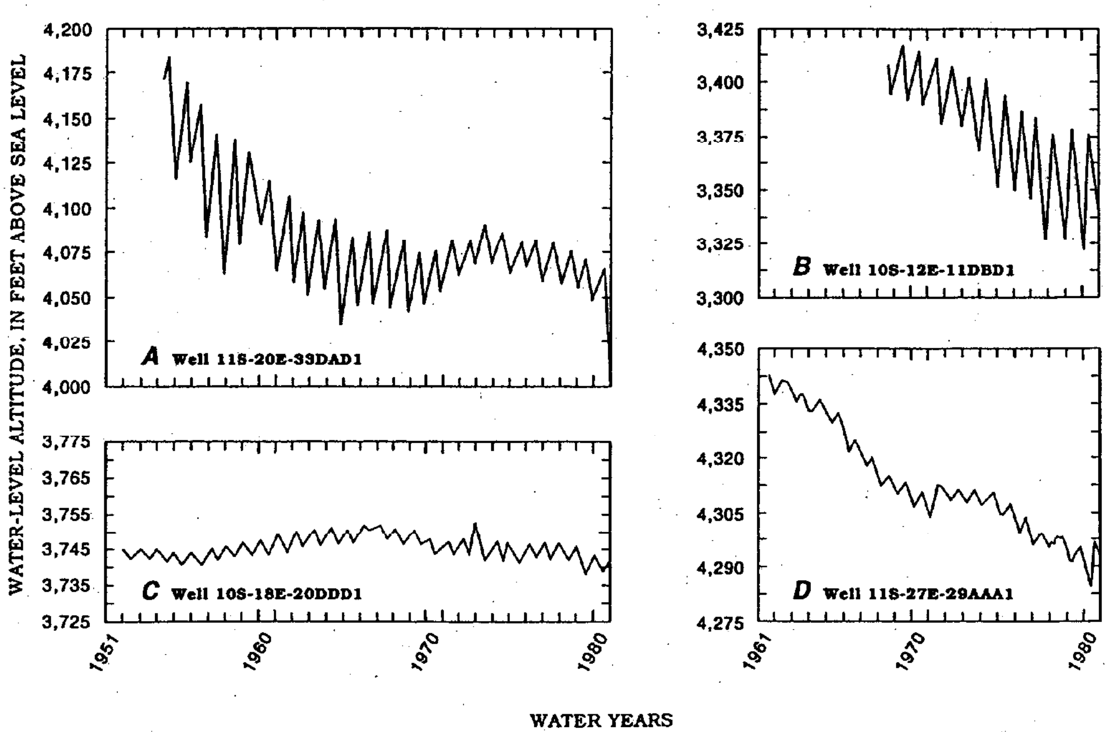


FIGURE 46.—Long-term changes in water levels in selected wells, southern part of the eastern Snake River Plain, water years 1951–80.

TABLE 14.—*Ground-water budgets for the western Snake River Plain, water years 1930–80*

[Values in thousands of acre-feet]

Water year	A Surface-water diversions (minus irrigation-return flow)	B Tributary drainage basins: ground-water discharge	C Consumptive use of diverted or pumped water	1 Recharge from irrigation and tributary drainage basins (*A*+*B*-*C*)	2 Recharge from precipitation on the western plain	Total recharge (1 + 2)	Discharge	Change in ground-water storage: Annual	Change in ground-water storage: Cumulative
1930	1,790	100	1,050	840	30	870	1,000	-130	-130
1931	1,500	100	950	650	30	680	920	-240	-370
1932	2,370	100	1,140	1,330	40	1,370	1,050	320	-50
1933	2,270	100	1,160	1,210	30	1,240	1,040	200	150
1934	2,010	100	1,150	960	40	1,000	980	20	170
1935	2,310	100	1,160	1,250	30	1,280	1,050	230	400
1936	2,310	100	1,170	1,240	40	1,280	1,140	140	540
1937	2,180	100	1,230	1,050	20	1,070	1,100	-30	510
1938	2,480	100	1,280	1,300	220	1,520	1,240	280	790
1939	2,290	100	1,250	1,140	40	1,180	1,270	-90	700
1940	2,270	100	1,290	1,080	130	1,210	1,290	-80	620
1941	2,350	100	1,360	1,090	40	1,130	1,290	-160	460
1942	2,360	100	1,380	1,080	80	1,160	1,290	-130	330
1943	2,530	100	1,400	1,230	240	1,470	1,380	90	420
1944	2,280	100	1,410	970	30	1,000	1,240	-240	180
1945	2,400	100	1,420	1,080	100	1,180	1,220	-40	140
1946	2,510	100	1,430	1,180	160	1,340	1,260	80	220
1947	2,570	100	1,440	1,230	40	1,270	1,260	10	230
1948	2,470	100	1,450	1,120	40	1,160	1,220	-60	170
1949	2,620	100	1,460	1,260	30	1,290	1,250	40	210
1950	2,690	100	1,470	1,320	60	1,380	1,320	60	270
1951	2,770	100	1,480	1,390	100	1,490	1,350	140	410
1952	2,810	100	1,520	1,390	140	1,530	1,360	170	580
1953	2,920	100	1,540	1,480	40	1,520	1,360	160	740
1954	3,050	100	1,550	1,570	30	1,600	1,340	260	1,000
1955	2,800	100	1,570	1,330	30	1,360	1,270	90	1,090
1956	3,050	100	1,580	1,570	190	1,760	1,350	410	1,500
1957	2,920	100	1,590	1,430	250	1,680	1,420	260	1,760
1958	2,960	100	1,600	1,460	200	1,660	1,460	200	1,960
1959	2,960	100	1,620	1,440	30	1,470	1,450	20	1,980
1960	3,120	100	1,640	1,580	50	1,630	1,460	170	2,150
1961	2,800	100	1,660	1,240	40	1,280	1,380	-100	2,050
1962	2,980	100	1,680	1,400	30	1,430	1,450	-20	2,030
1963	2,950	100	1,710	1,340	40	1,380	1,450	-70	1,960
1964	3,040	100	1,740	1,400	50	1,490	1,450	40	2,000
1965	3,080	100	1,760	1,420	180	1,600	1,460	140	2,140
1966	3,160	100	1,820	1,440	30	1,470	1,360	110	2,250
1967	3,150	100	1,830	1,420	40	1,460	1,380	80	2,330
1968	3,160	100	1,880	1,380	40	1,420	1,400	20	2,350
1969	3,290	100	1,880	1,510	200	1,710	1,460	250	2,600
1970	3,240	100	1,880	1,460	280	1,740	1,520	220	2,820
1971	3,310	100	1,890	1,520	250	1,770	1,610	160	2,980
1972	3,260	100	1,900	1,460	210	1,670	1,600	70	3,050
1973	3,270	100	1,940	1,430	110	1,540	1,600	-60	2,990
1974	3,420	100	2,010	1,510	170	1,680	1,670	10	3,000
1975	3,410	100	2,120	1,390	180	1,570	1,720	-150	2,850
1976	3,440	100	2,130	1,410	170	1,580	1,710	-130	2,720
1977	2,990	100	2,140	950	10	960	1,440	-480	2,240
1978	3,450	100	2,140	1,310	280	1,590	1,520	70	2,310
1979	3,400	100	2,150	1,350	50	1,400	1,500	-100	2,210
1980	3,400	100	2,150	1,350	170	1,520	1,530	-10	2,200

e attributed to periods of above- and below-normal recipitation. The steady increase in storage in the 1950's can be attributed to the availability of addi- ional water for irrigation after completion of Cas- ade Reservoir in 1948, Anderson Ranch Reservoir in 1950, C.J. Strike Reservoir in 1952, and Lucky Peak ake in 1954. Ground-water storage increased in the arly 1970's due to above-normal precipitation but decreased substantially in 1977 due to below-normal recipitation. A 5-year moving-average curve for Oc- ober-to-March precipitation shows some of the same general trends.

Hydraulic heads in individual aquifers are not nec- ssarily indicative of changes in ground-water stor- age in the western plain. Water levels in most areas of the Boise and Payette River valleys are believed to have risen almost to 1980 levels by the 1920's, soon after irrigated acreage stabilized. However, Young and Norvitch (1984) noted that water levels declined from 1971 to 1982 in parts of northern Owyhee, southern Elmore, and southern Canyon Counties. In a few scattered wells just south of the Snake River, water-level rises probably resulted from increased re- charge from seepage of water pumped from the Snake River for irrigation.

Analysis of water-level data indicates that, in plac- es, declines in recent years (1953–80) probably are due to ground-water pumpage. For example, water levels in wells 7S-5E-19CCC1 in northern Owyhee County and 2N-1W-7BBC1 in southern Canyon County (pl. 1, sites W22 and W24, respectively) have declined over the last 20 to 30 years as a result of pumping (fig. 49*A*, *C*). Well 7S-5E-19CCC1 is com- pleted in Idavada Volcanics of Tertiary age at a depth of 760 ft. Well 2N-1W-7BBC1 is completed in basalt of the Snake River Group at a depth of 103 ft. Water levels in well 2N-1W-7BBC1 show a slight recovery from the drought year of 1977. Water levels in well 5S-8E-36CCC1 in southern Elmore County (pl. 1, site W21; fig. 49*B*), completed in alluvium at a depth of 90 ft, generally correspond to the cumulative change in ground-water storage.

Water levels in well 3S-1E-35DAC1 in northern Owyhee County (pl. 1, site W23; fig. 49*D*) rose rapid- ly from 1970 to 1976. Increased ground-water storage may be attributable to irrigation of additional acre- age with water pumped from the Snake River and to several years of above-normal precipitation.

SUMMARY AND CONCLUSIONS

Because the Snake River Plain is semiarid, irriga- tion is necessary for successful agricultural produc-

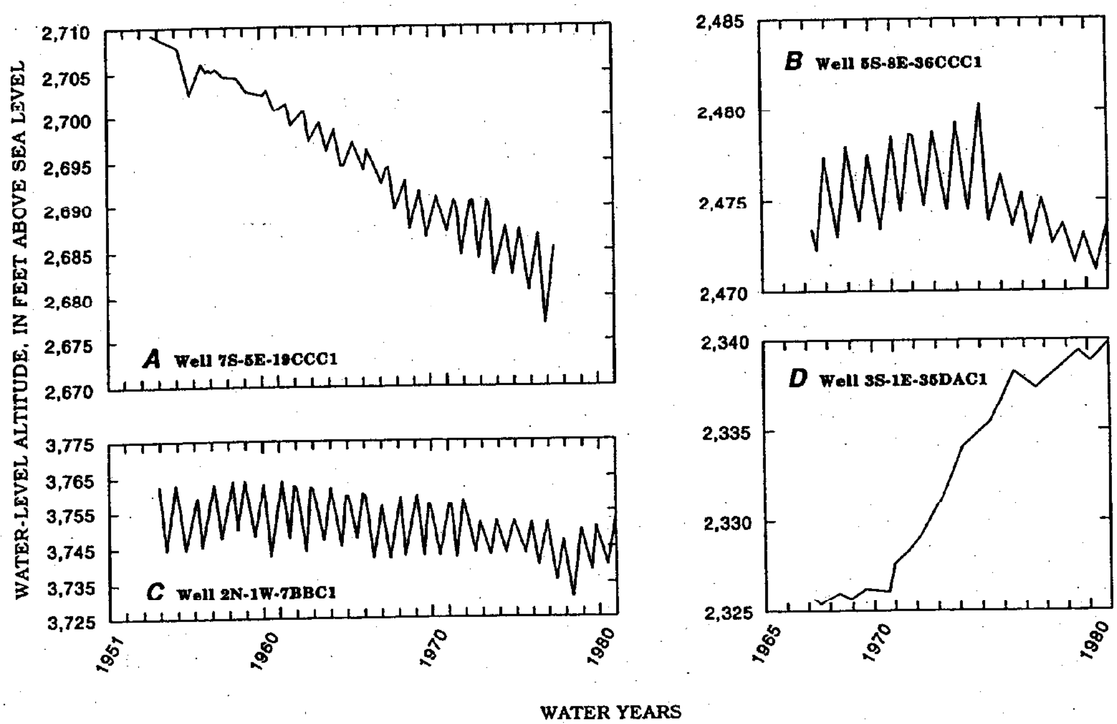


FIGURE 49.—Long-term changes in water levels in selected wells, western Snake River Plain, water years 1951–80.

increase in ground-water storage in the western plain was about 3 million acre-ft.

In water year 1980, ground-water discharge and recharge in the western plain were both about 1.5 million acre-ft. Most ground-water discharge is to the Snake and Boise Rivers and to irrigation drains in the Boise River valley. A large part of the annual ground-water discharge is during the irrigation season.

Long-term changes in ground-water discharge and recharge and ground-water storage that were quantified during this study are generally attributable to 100 successive years of irrigation on the Snake River Plain. Changes in the amount of ground-water discharge to the Snake River in the eastern part of the plain is directly related to changes in net recharge due to irrigation water. Ground-water storage has increased and decreased as a result of changes in irrigation practices. Short-term changes in ground-water recharge and discharge and ground-water storage also are influenced by variations in annual precipitation. Less surface water was available for irrigation when precipitation was below normal.

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